DESIGN STUDY AND MULTI-PARTICLE TRACKING SIMULATION OF THE IH-DTL WITH KONUS BEAM DYNAMICS FOR KHIMA PROJECT

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Abstract

The Korea Heavy Ion Medical Accelerator (KHIMA) project of the Korea Institute of Radiological and Medical Sciences (KIRAMS) has developed heavy ion medical accelerator. The injector system of the accelerator for the KHIMA project is composed of a low energy beam transport line (LEBT), radio frequency quadrupole (RFQ), interdigit H-mode drift tube linac (IH-DTL) and medium energy beam transport line (MEBT). The IH-DTL is designed with KONUS beam dynamics and KONUS indicates a combined 0 degree structure. Optimization aims are to increase the quality of the beam and to reduce the beam loss. We performed KONUS beam dynamics design and multi-particle tracking simulations of the IH-DTL with LORASR and TraceWIN codes.

INTRODUCTION

Radio frequency quadrupole (RFQ) and interdigit H-mode drift tube linac (IH-DTL) in the injector system of the Korea Heavy Ion Medical Accelerator (KHIMA) project is used for acceleration of $^{12}C^{4+}$ beam as shown in Fig. 1 [1].

The IH-DTL of KHIMA injector system is similar to those of other medical accelerators such as the Heidelberg Ion-Beam Therapy Centre (HIT) in Europe and the Centro Nasionale di Adroterapia Oncologica (CNAO) in Italy, but the IH-DTL of KHIMA has two tanks while the IH-DTLs of the HIT and CNAO accelerators have only one tank. In the case of two tanks, it is convenient to perform the commissioning because the lengths of each tank are shorter and an quadrupole magnet is located on the outside between two tanks.

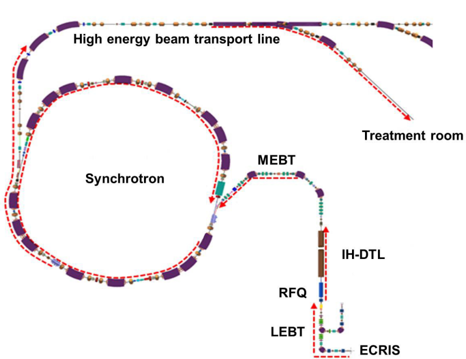

Figure 1: Layout of the KHIMA project.

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Principle of KONUS Beam Dynamics

There are various methods to focus and accelerate the beam in IH structures, for example an alternating-phase-focused (APF) linac, an interdigital H-mode permanent-magnet quadrupoles (IH-PMQ) and combined 0 degree structure (KONUS) [2]. For the KHIMA project, the IH-DTL with KONUS beam dynamics, which is the abbreviation for Kombinierte Null Grad Struktur in German and means a combined 0 degree structure, is adapted.

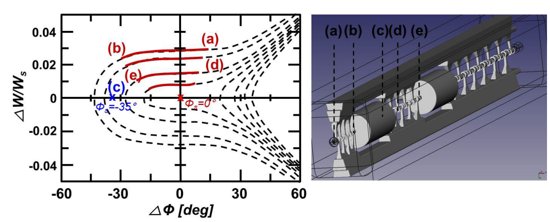

Figure 2: Beam bunch center motion along the KONUS period in the $\Delta W/W_s - \Delta\phi$ phase space (W_s : synchronous particle energy, ΔW : the difference between bunch centroid energy and synchronous particle energy, ϕ_s : synchronous phase).

The KONUS period consists of three sections, which are acceleration ((a)-(b) or (d)-(e) in Fig. 2), transverse focusing ((b)-(c) in Fig. 2) and rebunching ((c)-(d) in Fig. 2) section. The acceleration efficiency is improved because the beam in the acceleration section (ϕ_s=0°) is injected near the 0 degree RF phase. The beam is transversely focused by solenoids or quadrupoles in transverse focusing section and is rebunched by several gaps in rebunching section (ϕ_s=-35°).

BEAM OPTICS DESIGN

The optimization aims of the beam optical design for the IH-DTL are to increase the transmission efficiency and to decrease the beam emittance growth, beam loss and total length of the IH-DTL during the acceleration of $^{12}C^{4+}$ beam from 0.4 MeV/u to 7 MeV/u [3].

LORASR Code

LORASR is abbreviated from LOngitudinale und RAdiale Strahldynamikrechnungen mit Raumladung in German, which means longitudinal and radial beam dynamics simulation including space charge effect, and is optimized for the DTL design with KONUS beam dynamics. The simulation for the beam optics design is performed with 5,000 particles and Twiss parameters of initial beam distributions used for

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optics design are equal to those of the beam at the end of RFQ.

Simulation Results

The designed IH-DTL is composed of one buncher, two quadrupole doublets (QD), four quadrupole triplets (QT) and two IH-DTL tanks (IH-DTL 1, IH-DTL 2). The buncher, IH-DTL 1 and IH-DTL 2 include 2, 37 and 19 gaps, respectively. The $^{12}C^{4+}$ beam with beam current 0.2 emA is accelerated up to 7 MeV/u at 200 MHz operation frequency and duty cycle is less than 0.1 %, as shown in Fig. 3.

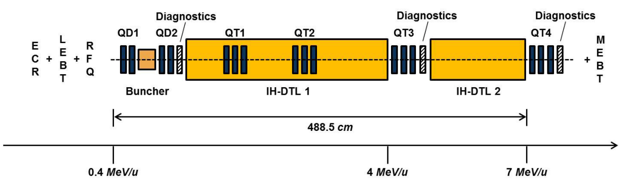

Figure 3: Layout of IH-DTL.

IH-DTL 1 has three KONUS periods in the length of 2.78 m and IH-DTL 2 has only one KONUS period in the length of 1.46 m. Fig. 4 shows that beam bunch center motion at each gaps acts on KONUS beam dynamics.

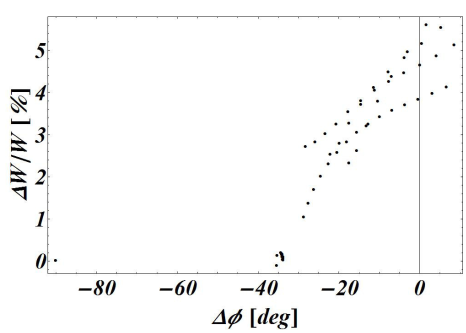

Figure 4: Longitudinal bunch center motion at each gap along the KONUS period.

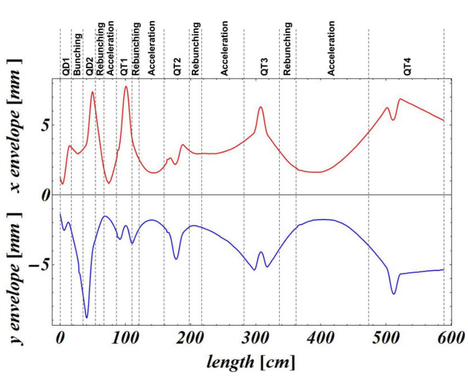

Figure 5: Transverse 100 % envelopes along IH-DTL (LORASR code).

Figs. 5 and 6 represent transverse and longitudinal 100 % envelopes along IH-DTL, respectively. The QDs and QTs, which have radius of 1 cm, are installed in order to transversely focus the beam and match the beam parameters. The transverse beam envelopes are less than 1 cm at all sections. Fig. 6 shows that the beam at the entrance of the acceleration section has surplus energy and is injected to acceleration section.

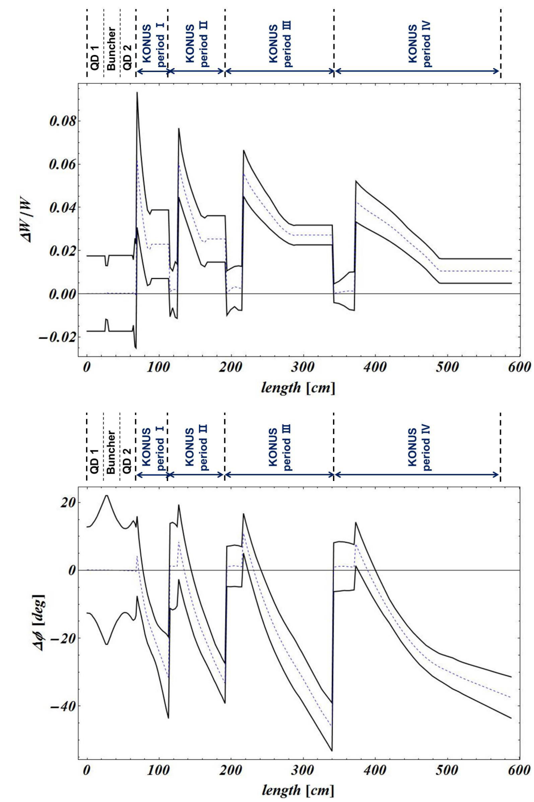

Figure 6: Longitudinal 100 % envelopes along IH-DTL (LORASR code).

The upper and bottom in Fig. 7 present input and output beam distributions of IH-DTL. As shown in Fig. 8, the normalized RMS emittance in horizontal, vertical and longitudinal directions are increased by 7.6 %, 6.7 % and 29 %, respectively.

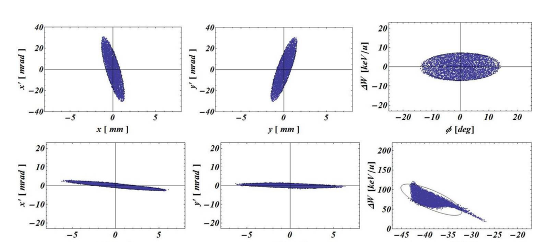

Figure 7: Input and output beam distributions (LORASR code).

Total length of IH-DTL is about 4.89 m and the transmission efficiency is 100 %. The maximum value of effective voltages used in each gap is 0.554 V. The maximum and minimum values of quadrupole field gradients are 100 T/m and 75 T/m, respectively.

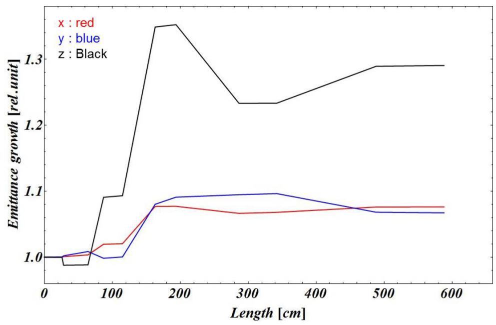

Figure 8: Normalized RMS emittance growths (LORASR code).

MULTI-PARTICLE TRACKING

The simulation results with LORASR code are restricted by the number of particles. Thus, it is essential to perform the beam tracking simulation with TraceWin code for more quantitative results and cross-checking.

TraceWin Code

TraceWin code allows to perform tracking with the beam distributions that are produced by the simulation for LEBT and RFQ.

Simulation Results

The upper and bottom in Fig. 9 represent input and output beam distributions of the IH-DTL. Initial number of particles is 49,931 and the number of particles at the end of IH-DTL is 49,260. The beam loss occurs by 1.34 % because of the beam tail formed in rebunching section.

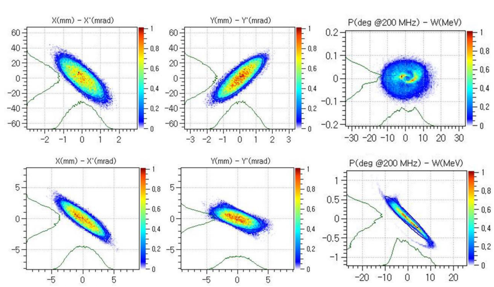

Figure 9: Input and output beam distributions (TraceWin code).

Figs. 10 and 11 present transverse and longitudinal 100 % envelopes along the designed IH-DTL, respectively. The transverse envelopes are similar to simulation results with LORASR code, but the longitudinal envelopes differ from the simulation results with LORASR due to beam tail.

Fig. 12 shows that the normalized RMS emittance growths in horizontal, vertical and longitudinal directions are about 0.13 %, 5.46 % and 56.6 %, respectively. The transmission efficiency is 98.7 %.

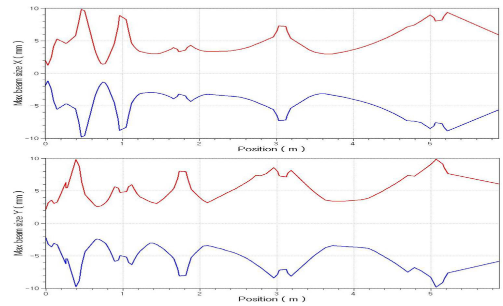

Figure 10: Transverse 100 % envelopes along IH-DTL (TraceWin code).

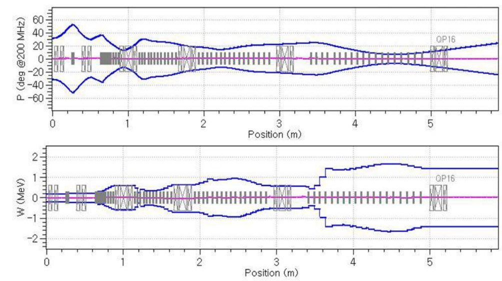

Figure 11: Longitudinal 100 % envelopes along IH-DTL (TraceWin code).

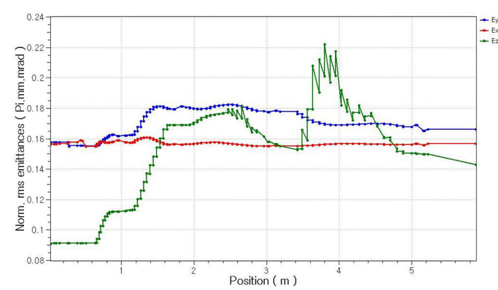

Figure 12: Normalized RMS emittance growths (TraceWin code).

CONCLUSION

The beam optics design and multi-particle tracking simulation of IH-DTL for KHIMA project is performed with LORASR and TraceWin codes. IH-DTL consists of two tanks, which include total 58 gaps in the length of 4.89 m. $^{12}C^{4+}$ beam is accelerated from 0.4 MeV/u to 7 MeV/u. The differences between LORASR and TraceWin code on simulation results of the beam emittance growth and transmission efficiency are caused by beam tail that is generated in initial beam distributions.

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