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DYNAMICS STUDY OF A DRIFT TUBE LINAC FOR BOTH HEAVY IONS AND PROTON*

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Abstract

An accelerator complex for Space Environment Simulation and Research Infrastructure (SESRI) has been designed by Institute of Modern Physics (IMP) and will be constructed in Harbin Institute of Technology (HIT). This accelerator consists of an ECR ion source, a linac injector, a synchrotron and 3 research terminals. As an important part of the complex, the linac injector should provide both proton and different kinds of heavy ions, from helium to bismuth, with energy of 5 MeV and 1 MeV/u respectively for the synchrotron. In order to provide beams with the mass to charge ratio (A/Q) range from 1 – 6.5(for proton to $^{209}Bi^{32+}$) by only one linac injector, a special solution of the main acceleration section DTL is carried out. The relevant dynamics calculations, such as beam matching, stripping process of the hydrogen molecule ion and beam energy spread reducing, are performed by Particle in Cell (PIC) method.

INTRODUCTION

In order to simulation and research the damage to the electronic equipment and organism on the spacecraft by high-energy particles in the universe, Harbin Institute of Technology (HIT) proposed building an accelerator based nuclear irradiation source named Space Environment Simulation and Research Infrastructure (SESRI). The accelerator complex of SESRI is designed and constructed by Institute of Modern Physics (IMP) which contains an ECR ion source, a linac injector, a synchrotron and 3 research terminals [1] as shown in Fig. 1. The ECR ion source can provide mostly all stable ions from proton to bismuth. These ions are accelerated by the linac injector to the injection energy of the synchrotron. The synchrotron accelerates different kinds of ions to specific energy and then slowing extracts them to the experiment terminals. The design of the linac injector must meet the preliminary requirements of the synchrotron, which can be seen in Table 1. For this linac injector, the main problem is how to accelerate very heavy ions like $^{209}Bi^{32}$ and lightest ion proton and make it more compact. Between the linac injector and the synchrotron, there is a long beam transport line used for vacuum degree transition.

According to the project requirement, preliminary dynamics design of the DTL is finished. And then, Beam dynamics tracking with a PIC simulation code for different operation mode alone the main acceleration section is accomplished. The simulation takes beam matching into account and verifies the preliminary design. On the other hand, effects of stripping foil on the hydrogen molecule ion are studied. A short beam transport line used for reducing the beam energy spread of proton and heavy ion is also designed in the PIC simulation.

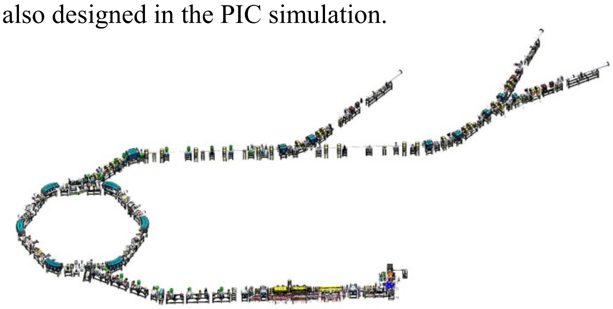

Figure 1: Integrated layout of SESRI accelerator complex.

Table 1: Inject Beam Parameters of the Synchrotron

Parameter	Value
Beam energy	1 MeV/u($^{209}Bi^{32+}$), 5 MeV (proton)
Energy spread	±0.3%
Transverse emittance	≤13πmm·mrad
Beam current	30 eμA($^{209}Bi^{32+}$), 300 eμA(proton)

PRELIMINARY DYNAMICS DESIGN OF THE DTL

The R/Q of the injection ion for the synchrotron ranges from 1 to 6.5 and it is too large for a normal conducting muticell linac which is because the cavity power range is squared of the R/Q. The whole RF system cannot operate stably in such a large power range. So in order to provide proton beam to the synchrotron, H_2^+ is accelerated to 1MeV/u by RFQ and DTL1 firstly and then be stripped to proton to continue accelerate by DTL2. In this way, the R/Q range of the RFQ and the first section of the DTL will be only from 2 to 6.5. Beam extract energy of the RFQ is set to 300 keV/u for H_2^+ and other heavy ions. The RF frequency is 108 MHz for the whole linac injector.

KONUS dynamics [2] concept and LORASR code [3] are adopted to make the preliminary dynamics design of the DTL for the linac injector. On the basis of the injection energy requirements of the synchrotron for proton and heavy ions, this linac injector contains two DTL cavities. All heavy ions including H_2^+ can be accelerated to 1 MeV/u by the DTL1 which contains an inner focusing quadrupole triplet. And DTL2 is only used to accelerate the proton from 1 MeV to 5 MeV. For heavy ions, the DTL2 is just regard as a drift section. Between the two

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DTLs, there must be a foil for stripping H_2^+ to proton. For simplicity, the effects of stripping foil on the H_2^+ are ignored in the preliminary design.

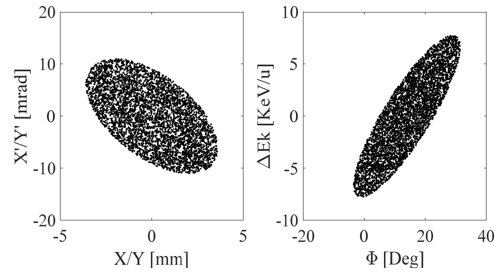

Figure 2: Phase space distribution at the entrance of DTL1.

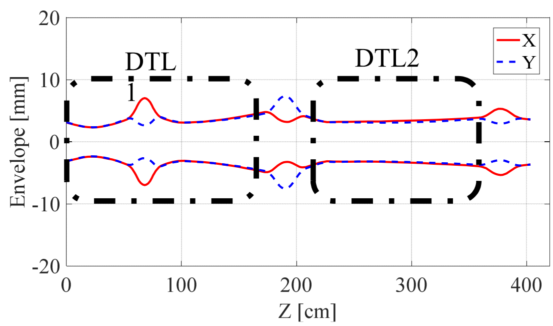

Figure 3: Beam transverse envelope in DTL1 and DTL2.

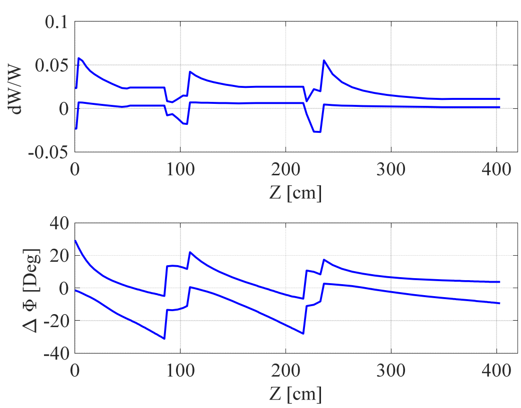

Figure 4: Energy spread and bunch length boundary along DTL1 and DTL2.

In the dynamics calculation, the tracking particle is set to be proton, but the maximum values of gap voltage and quadrupole magnet strength about DTL1 must be reasonable when $^{209}Bi^{32+}$ is accelerated. Kilpatrick factor is less than 2.1 and the maximum pole face electric field of all quadrupole magnets is not larger than 0.9T. Beam transverse and longitudinal phase space distribution at the entrance of DTL1 is set to uniform distribution which the RMS emittance is 0.2πmm·mrad and 0.45πns·keV/u respectively as shown in Fig. 2. Transverse envelope of 90% beam is shown in Fig. 3. DTL2 is followed by a quadrupole triplet. Energy spread and bunch length boundary of the beam relative to the synchronous particle can be seen in Fig. 4. The normalized RMS emittances relative increment is small in transverse but a little larger for the longitudinal as shown in Fig. 5. Nevertheless, the synchrotron cares more about the transverse emittance, especially the horizontal one, and beam energy spread. As Fig. 6, the minor axis of longitudinal phase ellipse is short and it will benefit for reducing the beam energy spread which will be discuss later.

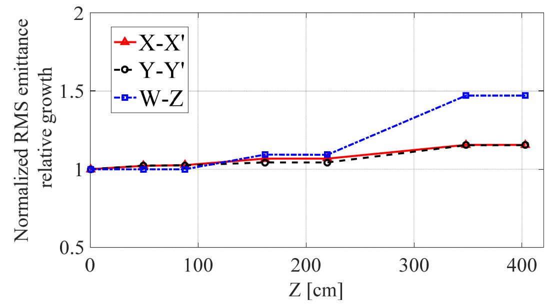

Figure 5: Normalized RMS emittances relative increment.

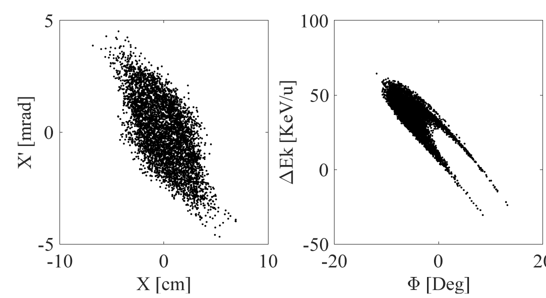

Figure 6: Phase space distribution at the exit of DTL2.

BEAM DYNAMICS TRACKING FOR $^{209}BI^{32+}$

The dynamics preliminary design of the RFQ has been finished and the phase space distribution of the extraction beam of the RFQ is shown in Fig. 7. Transverse and longitudinal normalized RMS emittance is 0.15πmm·mrad. Between the RFQ and DTL1, there is a 1.5 meter long beam transport line including 5 quadrupole magnets and a 2 gap buncher named Buncher1. When doing the simulation of $^{209}Bi^{32}$, DTL2 is treated as a drift section. The second buncher behind DTL2 is used for reducing the beam energy spread of heavy ions extracted from DTL1. The PIC simulation is performed by Beampath code.[4]

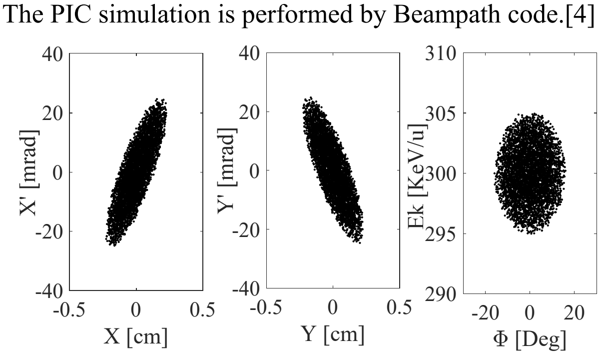

Figure 7: Beam phase space distribution at the exit of RFQ.

The transverse beam envelope, bunch length and energy spread along the main acceleration section are shown in Fig. 8. At the exit of the linac injector, energy spread of

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$^{209}Bi^{32}$ is less than ±0.3%. In this simulation, transverse normalized RMS emittance increases about 28% which is a little larger than preliminary design result. On the basis of the requirement of synchrotron, the normalized RMS emittance of heavy ion beam extracted from RFQ must be not more than 0.125πmm·mrad.

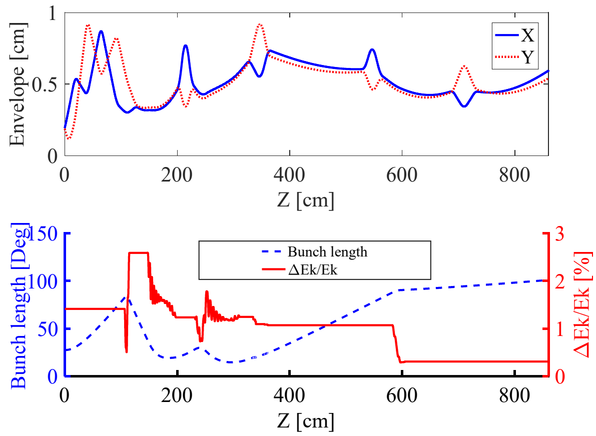

Figure 8: Beam envelope and energy spread along the main acceleration section.

BEAM DYNAMICS TRACKING FOR H_2^+/PROTON

Because the RFQ and DTL1 are designed for H_2^+ and the DTL2 is designed for proton, a stripping foil is needed to convert H_2^+ to proton. It will enlarge the transverse beam emittances and energy spread. On the other hand, the holistic beam energy would be lower slightly. These situations must be considered in dynamics tracking. According to literature research [5], a 15μg/cm^2 carbon foil is chose, and the stripping efficiency approaches 100%. Its influence on H_2^+ is calculated by LISE++ code as Table 2 [6].

Table 2: 1 MeV/u H_2^+ Stripping Results by LISE++

Parameter	Value
Energy loss	1.7 keV/u
Energy straggle	0.6 keV/u(1σ)
Angular straggle	1.47 mrad(1σ)
Lateral spread	1e-5 μm(1σ)

The dynamics tracking of 500 eμA H_2^+/proton is also performed by Beampath code. Monte Carlo method is adopted at the stripping foil. Buncher3 is placed behind DTL2 with a distance of 2.5 m for reducing the energy spread of proton. The transverse beam envelope, bunch length and energy spread of H_2^+/proton can be seen in Fig. 9. Energy spread of 100% beam is too large for the synchrotron. But after removing the 20% particles with large energy spread, the rest of beam can satisfy the energy spread requirement of the synchrotron. Transverse emittances of H_2^+/proton are shown in Fig. 10. Because the injection design of synchrotron demands painting in horizontal direction, vertical emittance growth is acceptable. Based on the dynamics tracking, proton beam extracted by the linac injector can meet the design target.

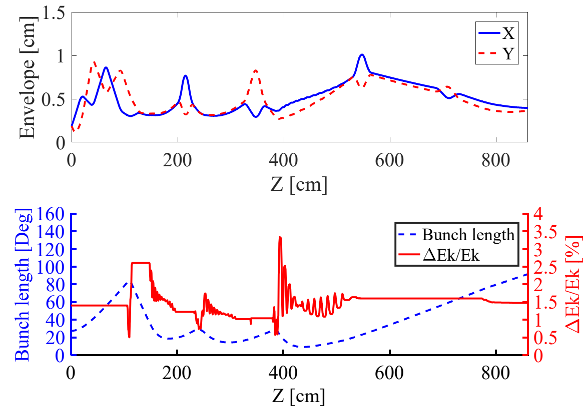

Figure 9: Beam envelope and energy spread of H_2^+/proton.

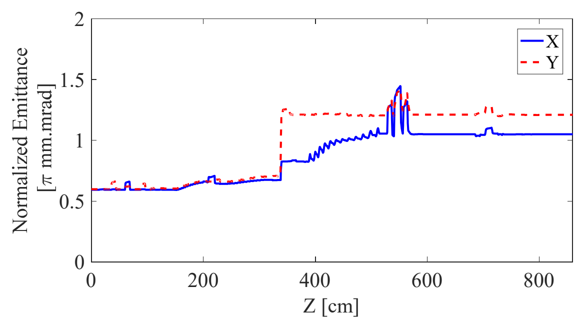

Figure 10: Normalized emittances of H_2^+/proton.

CONCLUSION

Preliminary design of the DTL for the linac injector of SESRI complex has been finished. Beam matching section between RFQ and DTL1, stripping foil and energy spread reducing section are design and simulated. The transverse emittance and energy spread of extraction beam of this linac injector meet the requirements of synchrotron basically. Formal design scheme and the RF structure design are in the optimization.

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