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OVERALL CONCEPT DESIGN OF A HEAVY-ION INJECTOR FOR XiPAF-UPGRADING*

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Abstract

Xi'an 200 MeV proton application facility (XiPAF), which consists of one 230 MeV proton synchrotron and irradiation station, has finished beam commissioning. XiPAF will be upgraded to provide a heavy-ion beam with a heavy-ion injector. The application of the facility will be expanded to cover the research of single event effects for protons and heavy-ions. In this paper, the overall concept design of a heavy-ion injector for XiPAF-upgrading is presented. The appended injector consists of an electron cyclotron resonance (ECR) heavy-ion source, a low energy beam transport line (LEBT), a radio frequency quadrupole (RFQ), an interdigital H-mode drift tube linac (IH-DTL), and a linac to ring beam transport line (LRBT). The mass charge ratio can be up to 6.5. The RFQ can accelerate heavy ions to 400 keV/u, and the DTL can accelerate the ions to 2 MeV/u, which can meet the requirement of the synchrotron.

INTRODUCTION

Xi'an 200 MeV proton application facility (XiPAF) [1, 2] is currently composed of a negative hydrogen ion linac, a medium energy beam transport line (MEBT), a proton synchrotron, a high energy beam transport line (HEBT), and an experimental target station.

It can provide 60 ~ 230 MeV proton beams and is mainly used for proton single event effect (SEE) simulation. The project was started in 2014. The beam commissioning of the negative hydrogen ion linac [3,4] and proton synchrotron [5] has been carried out in 2019.

To expand the application, XiPAF will be upgraded to provide a heavy-ion beam with an appended heavy-ion injector. Based on the proton synchrotron at present, the heavy-ion injector will be added to provide heavy ions with a charge mass ratio in the range of 1/2 ~ 1/6.5, and extract the maximum energy of 4 MeV /u (charge to mass ratio < 1/4) and 14 MeV/u (charge to the mass ratio ≥ 1/4) heavy ion beam, expanding the application to cover the research of SEE for protons and heavy-ions.

The injector consists of an electron cyclotron resonance heavy-ion source (ECRIS), an LEBT, an RFQ, an IH-DTL, and a linac to ring beam transport line (LRBT). The RFQ can accelerate heavy ions to 400 keV/u, and the IH-DTL can accelerate the ions to 2 MeV/u, which can meet the requirement of the synchrotron.

REQUIREMENT OF HEAVY-ION INJECTOR

The requirement parameters of the injector are listed in Table 1. Because there are various kinds of heavy ions, C^{5+} ions with the largest charge mass ratio and Au^{30+} ions with the smallest charge mass ratio are selected for subsequent optimization design. The sketch diagram of the whole injector is shown in Fig. 1.

Table 1: Design Parameters of the Heavy-ion Injector

Parameter	Value
Ion type	C^{5+} ~ Au^{30+}
Charge-mass ratio	1/2 ~ 1/6.5
Output beam energy	2 MeV/u
Peak current exit of the ECRIS	100 eμA (C^{5+})/50 eμA (Au^{30+})
Injected current	≥ 1.3 pμA(C^{5+})/0.6 pμA(Au^{30+})
RF Frequency	108 MHz
Repetition rate	0.1 ~ 0.5 Hz
Beam pulse width	60 ~ 100 us

ION SOURCE AND LEBT

For heavy ions, it is necessary to use a heavy-ion source to produce heavy ions with a high charge state. ECRIS [6] can achieve a high charge state and high current at the same time. It has long service life, a stable operation state, and can work in pulse or CW mode. The ion source will produce heavy ions with different charge states, so it is necessary to use the analytical magnet to select heavy ions with high charge

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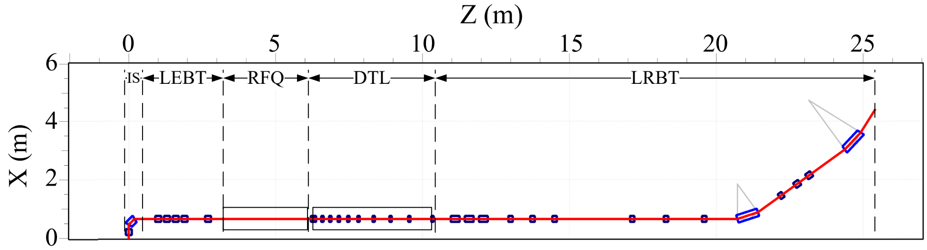

Figure 1: Sketch of the whole injector.

states. The ion source system mainly includes high charge ECR ion source and ion source beamline system including the analytical magnet.

The phase spaces of the heavy-ion beam in $x - x'$ and $y - y'$ planes are different after the analytical magnet. The function of LEBT is to transport and match the beam from the slit after the analytical magnet to the RFQ accelerator. The matching of LEBT mainly includes two parts: (1) symmetric beam matching; (2) RFQ entrance matching. Four quadrupole magnets are used to match the asymmetric beam to the symmetric one. The final matching at the entrance of the RFQ is completed by a solenoid. The beam parameters at the entrance of the symmetry matching section are measured directly by the emittance measurement system. The sketch diagram of the ion source system and the LEBT is shown in Fig. 2.

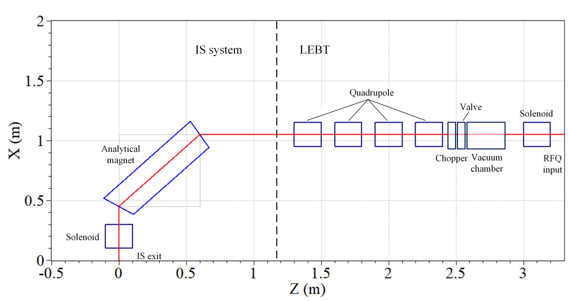

Figure 2: Sketch of the ion source system and the LEBT.

The 2.45 times RMS beam envelope in the LEBT is shown in Fig. 3, which is simulated with TraceWin [7]. The beam parameters at the exit of the LEBT meets the requirement at the entrance of the RFQ.

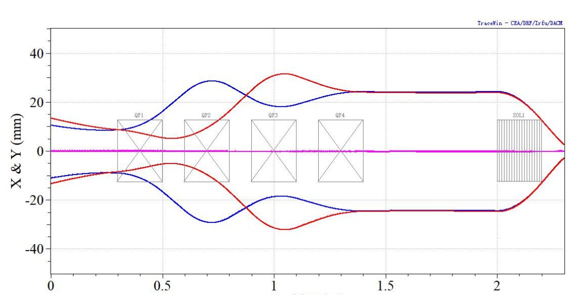

Figure 3: 2.45 times RMS beam envelope in the LEBT.

RFQ

RFQ accelerator immediately after the LEBT is to accelerate, bunch and focus the pulsed heavy ion beam generated from the ion source through the LEBT. After the energy reaches 0.4 Mev/u, it is directly injected into the IH-DTL accelerator to complete the requirements of the energy for the synchrotron.

Heavy-ion RFQ mainly adopts four-vane and four-rod structures. The main advantages of the four-vane RFQ cavity are uniform distribution of surface current density, convenient cooling, high mechanical strength, and stable structure. In this design, four-vane structure is used. To reduce the length of the cavity, a variable voltage design can be adopted, that is, the voltage between the vanes of RFQ changes with the increase of ion energy. The total length for the RFQ is 3.26 m with an input energy of 4 keV/u and exit energy of 400 keV/u. The beam dynamics simulated with RFQGen [8] in the RFQ is shown in Fig. 4.

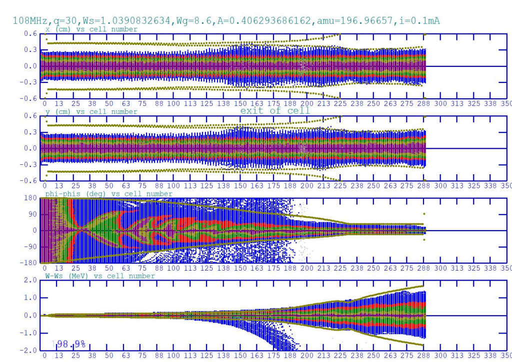

Figure 4: Beam dynamics in the RFQ (from top to bottom: envelope in x direction; envelope in y direction; envelope in phase; envelope in energy).

IH-DTL

Combined with the high shunt impedance characteristics of IH-DTL [9], the lateral stability of FD lattice and the longitudinal stability of conventional negative phase acceleration, a 108 MHz IH-DTL accelerator with the electro-magnet (IH-EMQ) [10, 11] is designed, as a part of XiPAF heavy ion injector.

IH-DTL uses a series of drift tubes in the RF resonant cavity. The center of the tube coincides with the center of the cavity. The heavy-ion beam with a certain initial

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velocity passes through the center of the drift tubes and advances along the centerline of the cavity. When the heavy ion beam passes through the gap between the two drift tubes, it accelerates under the action of the RF electric field. When the electric field is reversed, the heavy ion beam is just inside the drift tube, the drift tube shields off the electric field. After a series of drift tubes, the energy of the heavy-ion beam increases. A quadrupole lens is installed in every 3-4 drift tubes to provide a periodic focusing magnetic field to maintain the transverse stability of the beam, as shown in Fig. 5. The total length for the IH-DTL is 3.8 m with an input energy of 0.4 MeV/u and exit energy of 2 MeV/u.

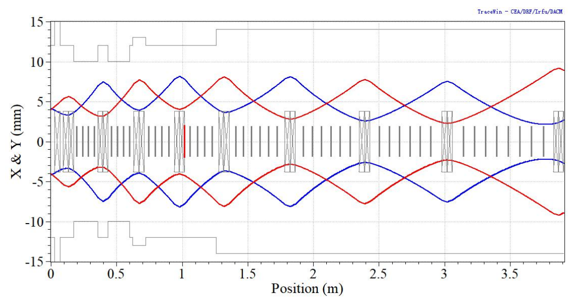

Figure 5: 2.45 times RMS beam envelope in the IH-DTL.

LRBT

The heavy-ion LRBT is located downstream of the DTL and connects the DTL and the synchronous ring. Its main function is to transport the heavy ion beam at the exit of the DTL to the injection point with the minimum beam loss and to realize the beam parameter matching at the injecton point. The beam is injected into the ring through the electrostatic deflector. The layout of the main components of LRBT is shown in Fig. 6.

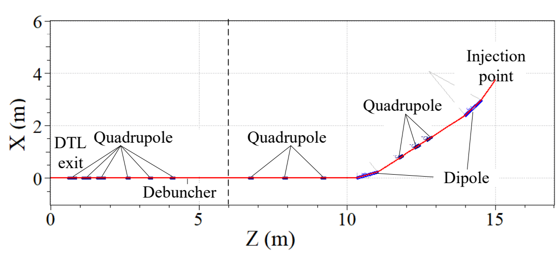

Figure 6: Layout of the main components of LRBT.

The transverse 2.45 times RMS envelope and horizontal dispersion of the beam in LRBT are shown in Fig. 7. The horizontal dispersion is zero at the injection point. The beam phase spaces at the exit of injection point are shown in Fig. 8. The total transmission from the exit of the LEBT to the injection point is 94%. The momentum spread at the injection point is within ±0.2%. 99% unnormalized emittance is 16.0 (x)/21.6 (y) π mm·mrad.

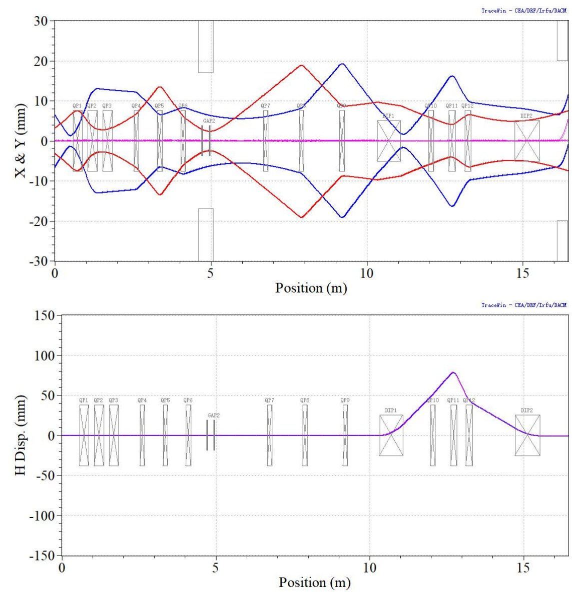

Figure 7: Beam dynamics in the LRBT (top: 2.45 times RMS beam envelope; bottom: horizontal dispersion).

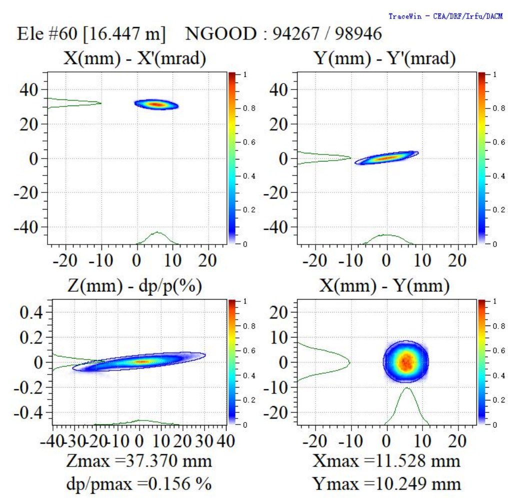

Figure 8: Beam phase spaces at the exit of injection point.

CONCLUSION AND FUTURE WORK

The heavy-ion injector consists of an ECR heavy-ion source, an LEBT, an RFQ, an IH-DTL, and an LRBT. The total transmission from the exit of the LEBT to the injection point is 94%.

The detailed design of the injector is undergoing. The engineering design of the injector will be carried out in the future.

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