BEAM DYNAMICS DESIGN OF THE MAIN ACCELERATING SECTION WITH KONUS IN THE CSR-LINAC PROPOSAL

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Abstract

The CSR-LINAC injector has been proposed in Heavy Ion Research Facility in Lanzhou (HIRFL). The linac mainly consists of two parts, the RFQ and the IH-DTL. The KONUS (Kombinierte Null Grad Struktur) concept has been introduced to the DTL section. In this paper, the re-matching of the main accelerating section will be finished in the 3.7 MeV/u scheme and the new beam dynamics design to 7 MeV/u will be shown. Through the beam re-matching, the relative emittance growth has been suppressed greatly along the linac.

INTRODUCTION

The Heavy Ion Research Facility in Lanzhou (HIRFL) has been upgraded with the HIRFL-CSR project at the end of the year 2007 and supplied 7000 hours operation time annually [1]. The injector of CSR consists of two cyclotrons, Sector Focusing Cyclotron (SFC) and Separator Sector Cyclotron (SSC). However, the linear accelerator becomes very popular as the injector of the next accelerator in recent years, such as, GSI-HIS, TRIUMF-ISAC, CERN-LINAC3, HIMAC and HIT. Due to larger beam acceptance, higher transmission and higher accelerating gradient, the linac injector can supply higher intensity and better quality beam. As the number of the applicants increasing rapidly and the experimental requirement improved, one new injector become most essential. The new injector called CSR-Linac has been proposed, which will make the operation time to increase by more than 5000 hours and attract more comprehensive physical experiments.

The CSR-LINAC injector will supply all kinds of heavy ion beam with 7 MeV/u for HIRFL-CSR, as shown in Fig 1. The charge to mass range is from 1/7 to 1/3 and the designed beam intensity is chosen to 3 mA. Both RFQ and DTL are essential in the whole linac scheme and the layout of the linac is shown in Fig.2. The beam will be accelerated to 300 keV/u in RFQ and then transported to 7 MeV/u in the main accelerating section. The main parameter of the CSR-LINAC is summarized in Table 1. The KONUS concept is introduced to the main accelerating section in order to get higher accelerating efficiency. The 3.7 MeV/u physics design scheme has been proposed when cooperation with Institute for Applied Physics (IAP) [2]. So only the beam dynamics design of the back section become one new objective. In this paper, the re-matching of the 3.7 MeV/u main accelerating section is firstly finished and then the 3.7 MeV/u to 7 MeV/u beam dynamics scheme is proposed completely.

Table 1: Main Parameters of the CSR-Linac

Q/A	1/3~1/7
Emittance (pi.mm.mrad)	0.4 (norm, 90%)
Frequency (MHz)	108.48/216.96
Beam current (emA)	3
Duration (ms)	3
Repetition (Hz)	10
RFQ input/output energy	4/300 (keV/u)
DTL input/output energy	0.3/7 (MeV/u)
Transmission(design)	>90%

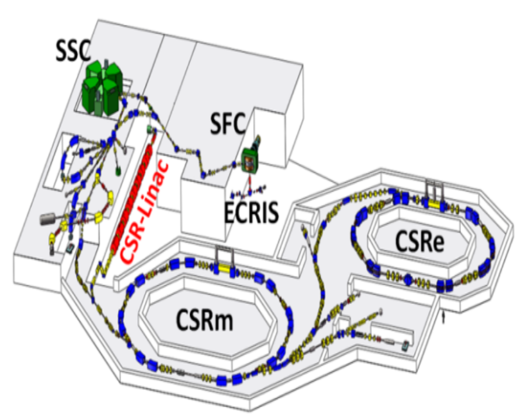

Figure 1: The layout of CSR-LINAC injector.

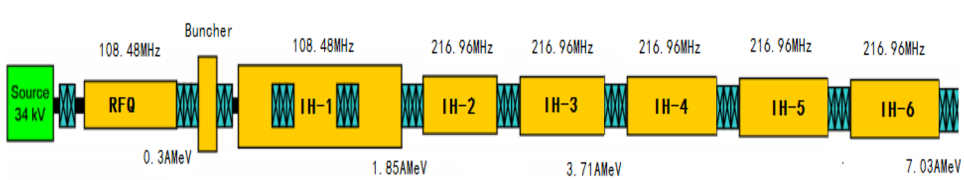

Figure 2: Preliminary layout of the 7 MeV/u CSR-LINAC proposal.

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RE-MATCHING OF THE 3.7 MeV/u SCHEME

The 3.7 MeV/u scheme of the CSR-LINAC proposal has been proposed four years ago. The LORASR code is applied to the beam dynamics of the KONUS concept in the main accelerating section. However, this scheme needs to be optimized to get better quality beam and larger error tolerance. As seen from Fig.1, the beam matching is not good along the whole DTL section, especially in the first DTL cavity. The beam mismatch will cause the emittance growth and beam coupling in the RF electric field. For matching from the exit of RFQ to the DTL section simply, the 5-Quadrupole scheme will be replaced by the 6-Quadrupole scheme in the MEBT section. The symmetrical beam matching method is adopted to reduce the beam coupling in the accelerating section. The emittance growth comparison between before and after the beam re-matching is shown in Fig.4. After the re-matching, the relative RMS emittance growth is reduced greatly in three phase space. The maximum envelope is reduced by 3 mm, which is benefit for alignment and suppressing the beam nonlinear effect, as show in Fig.3.

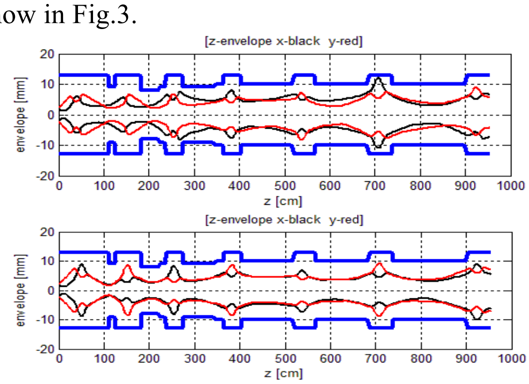

Figure 3: The beam envelope as the function of the position z before (upper) and after (bottom) the beam re-matching.

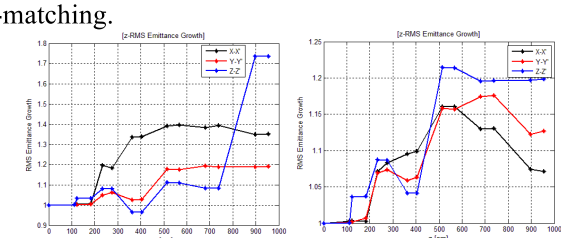

Figure 4: The relative emittance growth as the function of the position z before (left) and after (right) the beam re-matching.

UP TO 7 MeV/u BEAM DYNAMICS

The KONUS concept is applied for the 3.7 to 7 MeV/u beam dynamics scheme. LORASR is used as the only code for the KONUS concept [3]. The period structure concept is proposed in the KONUS beam dynamics design. A KONUS period is composed of three sections with separated function. The first section consists of a few gaps with a negative synchronous phase of typically from -25° to -35° and acts as a rebuncher. Then the beam is injected into the main accelerating section with surplus energy and phase compared with a synchronous particle. Finally, the multi-gap section is followed by the transverse focusing elements, such as the magnetic quadrupole triplets.

In the beam dynamics design of the KONUS period structure, it is very important to choose the key parameters [4], such as:

- The effective voltage distribution per section
- The radius and gap length per cell
- The gap number of the rebuncher section
- The gap number of the 0° section
- The starting phase and energy of the 0° section

The Choice of the Effective Voltage Distribution

The effective voltage per gap should be chosen to ensure that the spark don't appear during the commissioning and operation. The effective voltage mainly depends on the operation frequency, the tube radius and the gap length. The operation frequency is 108.48 MHz and 216.96 MHz in the main accelerating section, which corresponding to the spark electric field of 21.05 MV/m and 27.37 MV/m respectively, as 1.8 times of the Kilpatrick electric field is chosen. The CST STUDIO software is applied to research the relation between the peak electric field (E_p) and the maximum surface electric field ($E_{s,max}$). The optimized ratio $E_p/E_{s,max}$ depends on the tube radius, the gap length and the geometry of the pole. So the maximum peak electric field corresponding to the spark can be given at the different tube radius and gap length, as shown in Fig.5. The peak electric field distribution per section is also shown in the Fig.5 and below the maximum peak electric field. The scheme of the effective voltage distribution per section is reasonable.

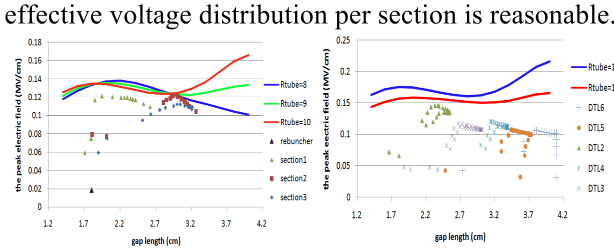

Figure 5: The dots stand for the peak electric field distribution per cavity at the frequency of 108.48 MHz (right) and 216.96 MHz (left). The lines mean the maximum peak electric field corresponding to the spark as the function of the gap length, at the tube radius of 8 mm (blue), 9 mm (green), and 10 mm (red).

The Choice of the Gap Number Per Section

The rebuncher section is used to bunch the beam in the longitudinal phase space. Generally, the synchronous phase is chosen to -35° and the gap number of this section depends on the focusing status in the transverse and longitudinal phase space. At the end of the rebuncher section, the beam should be focused at three directions so that transported through the 0° section effectively.

The choice of the starting phase and energy depend on the initial phase space distribution. A good choice should bring smaller emittance growth and reasonable output phase space distribution for the beam transport at the back of DTL section. In order to reduce the gap number of the rebuncher section, the phase spread is about 45° and the relative energy spread is around 1.5%. Because the larger focused strength in the longitudinal direction corresponds to the larger defocused strength in the transverse direction. In addition, the matching at both the transverse and longitudinal phase space is an important criterion for determining the gap number of the 0° section. The evolution of the reference particle in the longitudinal phase space is shown in Fig.6. As seen from this picture, the trajectory of the centre particle is anomalous in the longitudinal phase space. Because the beam upstream is difficult to matching the next KONUS period and the modification of the beam dynamics in the third DTL may be a good choice.

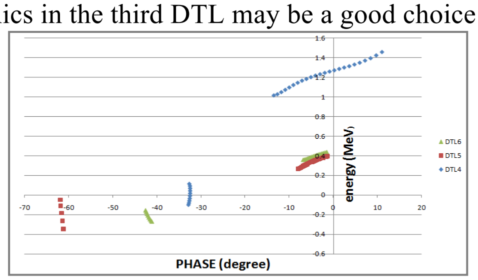

Figure 6: The evolution of the reference particle in the longitudinal phase space.

END-TO-END BEAM DYNAMICS

The end-to-end beam dynamics simulation will be shown in the following. Seen from the beam envelope evolution in Fig.7, there is a good beam matching and small envelope along the linac. The tube aperture is confirmed in the reasonable range. Figure 8 exhibits the phase space distributions in the input and output of the DTL section. The distribution in the input is rebuilt according to the phase space in the exit of RFQ. As seen from the distribution in the output, the longitudinal phase space has some filament caused by the non-linear field. And this will result in the longitudinal emittance growth, seen in Fig.9. The relative RMS emittance growth is 6.3%, 11.7% for x-x', y-y' phase space, and especially the emittance growth reaches 28.1% in the longitudinal phase space.

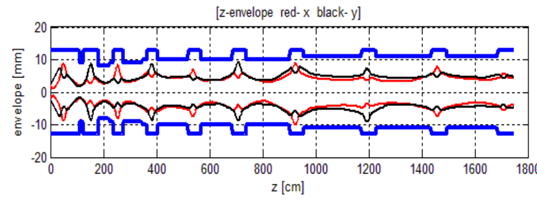

Figure 7: The x (red) and y (black) transverse envelope as a function of position z.

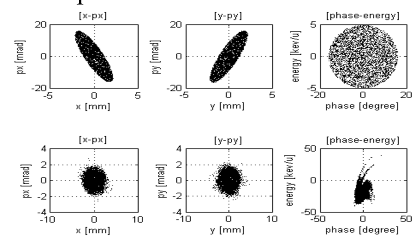

Figure 8: The phase space distribution at the entrance (upper) and exit (lower) of the DTL section.

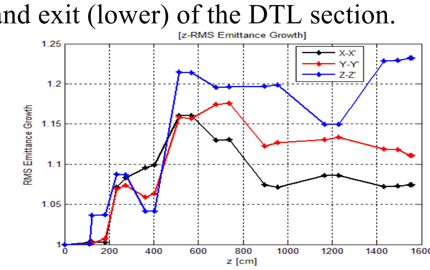

Figure 9: The relative emittance growth as a function of coordinate position z.

CONCLUSION

The beam re-matching of the 3.7 MeV/u beam dynamics scheme is proved advantageous for reducing the RMS emittance growth. It would be good idea to choose the symmetric beam during the transportation in the RF electric field. This method is proved valid through the 3.7 MeV/u beam dynamics design proposed by IAP. The 3.7 to 7 MeV/u scheme which only uses 3 cavities reveals that the KONUS structure has a high accelerating gradient. The end-to-end simulation shows that the whole beam dynamics design is a reasonable scheme.

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