CONCEPTUAL DESIGN OF LINEAR INJECTOR FOR SSC OF HIRFL

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Abstract

Heavy Ion Research Facility at Lanzhou (HIRFL) consists of two cyclotrons (SFC and SSC), one synchrotron (CSRm), and one storage ring (CSRe). The two cyclotrons are in series as the injector of the synchrotron. An additional LINAC injector for SSC is considered to increase the beam time at targets, named SSC-LINAC. The new injector consists of an RFQ, four IH-DTL tanks. A pre-buncher is in the front of RFQ with frequency of 13 MHz to match the RF frequency of SSC. TRACE-3D, PARMTEQm, LINREV, BEAMPATH, and DAKOTA are used to design, optimize, and simulate the acceleration structures of SSC-LINAC. The energy of 0.97 MeV/u with spread of ±0.5% and bunch length of 2.1 ns is achieved at the exit. These can match the ideal acceptance of SSC. A front-to-end simulation is done by BEAMPATH to benchmark the design.

INTRODUCTION

Heavy Ion Research Facility at Lanzhou (HIRFL) consists of four accelerators, a Sector Focusing Cyclotron (SFC), a Separator Sector Cyclotron (SSC), a cooling storage synchrotron (CSRm), and a cooling storage ring for experimental (CSRe). SFC and SSC started running in 1998. CSRm and CSRe started running in 2008 [1]. The four accelerators are in series. SFC is the injector of SSC. SFC can be an injector of CSR for light ions. SFC and SSC work together to be the injector of CSR for heavy ions. That cause low efficient beam time of the whole facility. A new linear injector for SSC, named SSC-LINAC, is being considered to improve it. To reduce cost, it is considered to use a fixed frequency LINAC to perform two special tasks. One is supplying middle mass ions for Super Heavy Elements (SHE) experiment, and the other is to inject heavy ions for CSR. Some specifications of SSC are listed in Table 1.

Table 1: Specifications of SSC in Two Modes

Parameters	Mode1	Mode2
Ions	$^{48}Ca^{7+}$ $^{56}Fe^{8+}$ $^{59}Ni^{9+}$ $^{70}Zn^{10+}$	$^{86}Ke^{14+}$ $^{136}Xe^{22+}$ $^{208}Pb^{33+}$ $^{238}U^{37+}$
A/q	~7	~6.4
Input energy (MeV/u)	0.541	0.962
RF frequency (MHz)	13.0035	13.0023
Harmonic Number	8	6
Output energy (MeV/u)	5.62	10.06
Expected beam intensity	>1 pμA	>1 eμA
Purpose	SHE	CSR injection

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DESIGN OF SSC-LINAC

It is shown on the table, in the two modes of SSC, the RF works with the same frequency of 13 MHz corresponding to 6 and 8 times of beam rotation frequency. That is the possibility to use a fixed-frequency LINAC to work with SSC to do the two tasks. A conceptual layout of SSC-LINAC working with SSC is shown on figure 1.

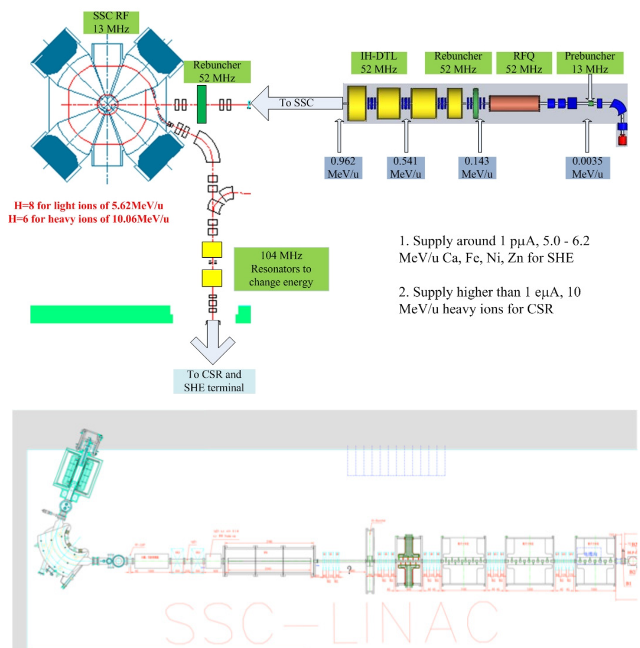


Figure 1: Conceptual design of SSC-LINAC.

Table 2: Major Specifications of SSC-LINAC

Parameters	Quantity	Unit
Beam frequency	13	MHz
Cavity frequency	52	MHz
A/q	<= 7	
Voltage of ion source	25	kV
Initial emittance (Norm.)	0.6	π.mm.mrad
Output energy of RFQ	0.143	MeV/u
Output energy 1	0.541	MeV/u
Output energy 2	0.962	MeV/u
Duty factor	100%	

The SSC-LINAC consists of a room temperature (RT) RFQ, four RT IH-DTL tanks, and three buchers. To match the frequency of SSC, a saw-tooth pre-buncher is at the Low Energy Beam Transport line (LEBT), just in the front of RFQ, to bunch beam into the frequency of 13 MHz. To reduce the length of LINAC, four times of frequency of 52 MHz is considered for the RFQ, the IH-DTLs, and the re-bunchers at the Middle Energy Beam Transport line (MEBT) and High Energy Beam Transport line (HEBT). The major specifications of SSC-LINAC are listed in the table 2. It operates in two modes. In the first mode, it extracts beam from the second IH-DTL tank with energy of around 0.541 MeV/u. In the second mode, it extracts beam from the last IH-DTL tank with energy of around 0.962 MeV/u. They can match with the injection beam energy listed in table1.

LEBT and RFQ

The beam optic of LEBT obtained by TRACE-3D is shown on figure 2. A double focusing dipole is used to analyze charge states. The downstream pre-buncher and three solenoids are used to match the entrance of RFQ.

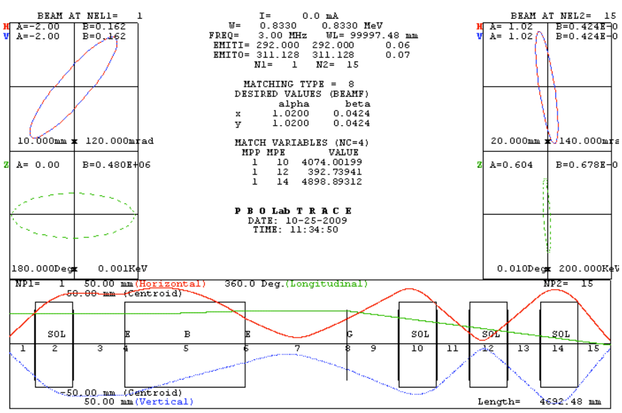


Figure 2: Beam optic of LEBT.

The RFQ is designed by PARMTEQm. Maximum beam current of 0.5 mA has been taken into account. Mechanical structure takes micro-wing type. Figure 3 shows the main parameters change with cell number [3].

Table 3: Parameters of RFQ

Parameters	Quantity	Unit
Frequency	52	MHz
Designed particle	$^{238}U^{34+}$	
Voltage	68	kV
Max surface electrical field	13.4	MV/m
Kilpatrick	1.487	
Minimum bore	0.467	cm
Average bore	0.707	cm
Maximum module	1.966	
Synchronous phase	-90 ~ -27.6	deg
Acceptance	1.2	π.mm.mrad
Pole length	250.01	cm
Cell number	146	
Emittance growth Ex	10.8%	
Emittance growth Ey	10.5%	
Longitudinal Emittance (rms)	1.54	π.keV/u.ns
Transmission	98.6%	

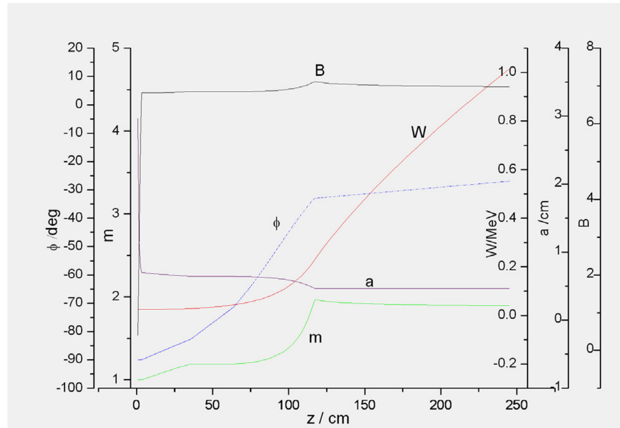


Figure 3: Parameters of RFQ change with cells.

MEBT and IH-DTL

This section has a re-buncher (RB) and four IH-DTL Tanks (T1~T4). Parameters of them are listed in table 4. In order to match the acceptance of SSC, an energy spread of less than ±0.5%, and a phase width of less than ±1.28 ns are required for the output beam bunch. The emittance in horizontal is less than 24 π.mm.mrad. The variable parameters of synchronous phases, gap voltages and strength of quadrupoles are optimized by mean of DAKOTA and LINREV together [2]. The emittance of initial beam are assumed to be 1.0 π.mm.mrad (normal.) in transversal and 2.7 π.keV/u.ns in longitudinal when we optimize all variable parameters.

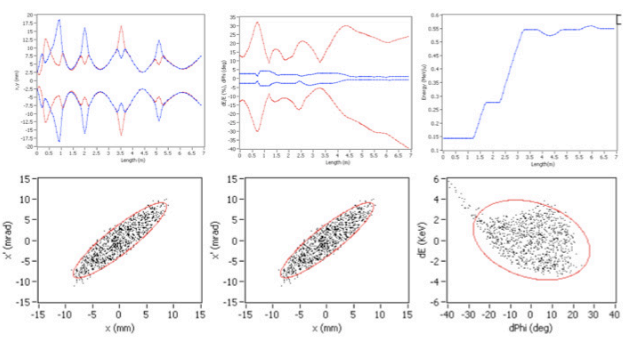
When the output energy is 0.97 MeV/u, the four DTL tanks works on full voltage listed in table 4. The particles left in $\Delta E/E = \pm 0.5\%$ and $\Delta\phi = \pm 20$ deg is 97% and emittance increment in x-direction is 18%, in y-direction is 27%. Longitudinal emittance is 5.1 π.keV/u.ns. It is within the acceptance of SSC. Beam transport envelope and output phase space are shown in figure 4 (b).

When output energy is 0.54 MeV/u, the tank T3 and T4 are used to be the buncher. The voltage of T3 is 24% of the full and synchronous phase is -118 deg. The voltage of T4 is 17% of the full and synchronous phase is -180 deg. Beam is accelerated and decelerated in T3 and T4, the output energy keeps as same as the output from T2. The particles left in longitudinal acceptance is 86% and emittance increment in x-direction is 18%, in y-direction is 16%. Longitudinal emittance is 5.6 π.keV/u.ns. Beam transport envelope and output phase space are shown in figure 4 (a).

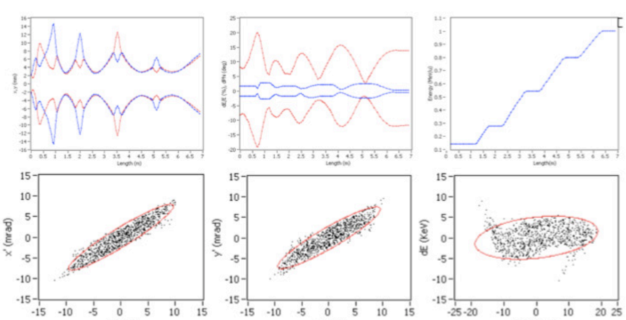
In order to reduce the interval length between DTL tanks, the short triplets are used. The effective length is 80 mm and 120 mm, separately. The aperture of quadrupoles is 50 mm. the max gradient of the long quadrupoles is 47 T/m, and the one of short quadrupoles is 44 T/m. The FeCo such as VACOFLUX 50 will be as the material of the quadrupoles.

Table 4: Parameters of DTL Tanks

	RB	T1	T2	T3	T4	Unit
Win	143	143	290	539	769	keV/u
Wout	143	290	539	769	976	keV/u
Tube radius	1.7	1.7	1.7	1.7	1.7	cm
Acc gaps	4	10	11	10	8	
Gap length	25	25	37	45	55	cm
Voltage	47.9	159	231	250	260	kV
Syn. phase	-90	-20	-25	-35	-25	deg
Tank length	21	64	110	110	110	cm



(a) 0.541 MeV/u



(b) 0.962 MeV/u

Figure 4: Beam transport of two modes

BENCHMARK AND BEAM SIMULATION

A simulation from the entrance of RFQ to the exit of the IH-DTL section is done by code BEAMPATH [4]. A benchmark of MEBT and IH-DTL section is shown in figure 5. It is shown that the envelopes of x, y, dE, and dPhi are roughly equivalent. The optimization results of DAKOTA with LINREV are reliable. It can be used to do further simulation.

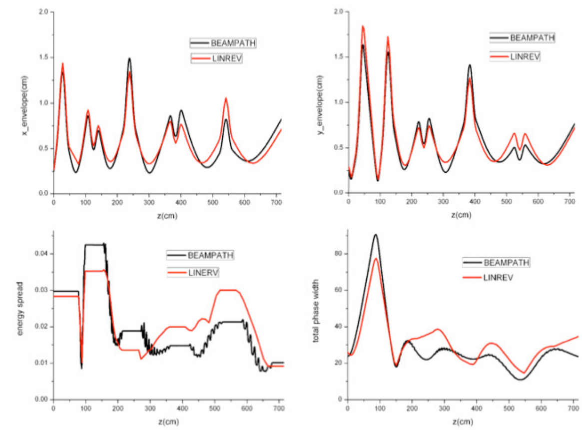


Figure 5: Benchmark results.

To evaluate the effect of space charge, beam intensity of 0 mA, 2 mA and 5 mA is taken into account. It is seen in figure 9 that the space charge is negligible after LEBT in SSC-LINAC.

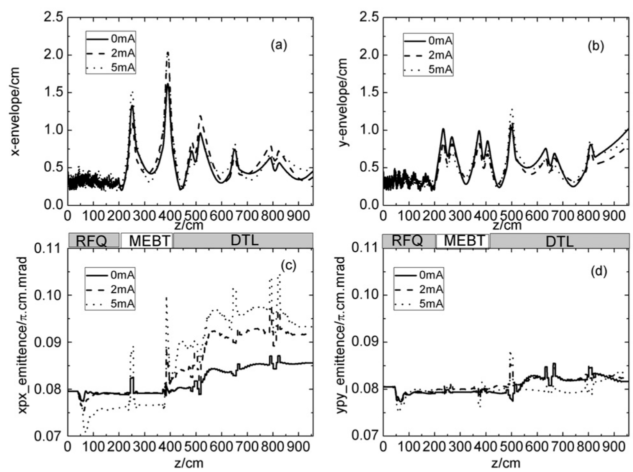


Figure 9: Space charge effect.

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