CONCEPTUAL DESIGN OF LEBT FOR C-ADS LINAC ACCELERATOR*

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Abstract

In order to avoid the hybrid ions like H_2^+, H_3^+ injecting into the RFQ and the residual gas H_2 tracing through the RFQ which may lead the RFQ cavity performance degradation, we present the conceptual design of the Low Energy Beam Transport (LEBT) for the China Accelerator Driven Sub-Critical reactor system (C-ADS) accelerator. The LEBT, consisting of one bending magnet and three solenoids and four short-drift sections, match the CW proton beam with 35KeV and 10mA to the entrance of a radio frequency quadrupole (RFQ). This bending LEBT can easily separate the unwanted ions. With the edge angles and one quadrupole to correct the beam asymmetry causing by the bending magnet, the simulation results meet the RFQ entrance requirements.

INTRODUCTION

A project named China Initiative Accelerator Driven Sub-Critical System (C-IADS) has been proposed to treat the spent nuclear fuel and began construction since 2011[1]. Under three years commissioning, the demo facility had accelerated 10mA CW proton beam to 2.56MeV, and recently 2.7mA CW proton beam had accelerated up to 5.17MeV. The layout of the demo facility is shown in the Fig 1.Some beam experiments in the CW mode had taken on the LEBT recently, and find that the component of H_2^+ and H_3^+ is about 32% and 5% at 1.6E-3Pa vacuum degree. And in our accelerator we find the transmission efficient from the LEBT to the RFQ is almost 62.5% (FC1=16mA, ACCT1=10mA). Another question is the H_2 removal from the ion source to the RFQ and even to the downstream superconducting cavity. Long-time operation with residual gas RFQ performance may decline has reported in paper, and residual gas removal to the SC may lead the cavity quench. This paper presents the detailed description about a new LEBT for C-ADS accelerator.

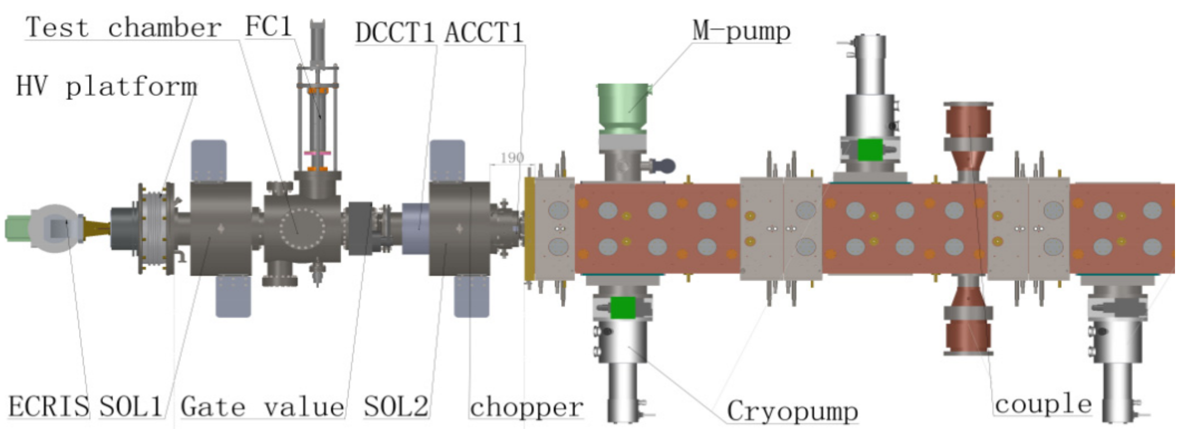

Figure 1: The layout of the ADS LEBT and parts of RFQ.

LEBT SYSTEM

The 10mA proton DC beam with the energy of 35KeV is extracted from a 2.45 GHz ECR ion source, after the LEBT transmission, focusing to the RFQ accelerator with the normalized RMS emittance at the entrance of RFQ less than 0.2 π.mm.mrad. The LEBT is used to transport and match the proton beam to the RFQ. Table 1 shows the key parameters of the front end to the RFQ which had met well with the downstream in the demo facility commissioning.

To meet the proton fraction requirement, a bending magnet and collimator have been considered to substantially reduce the contaminants, such as H2+ and H_3^+[3]. In order to decrease the beam divergence, we shorten the distance from the ion source to the first solenoid. And in order to reduce the space charge effect, the bending magnet is installed as close as possible to the first solenoid. Bending magnet will contribute the asymmetric ingredient to transverse axis, so we chose a little rotation angle into the magnet. After the separator, another two solenoids is used to match the Twiss parameters to the requirements. The next section will show the simulation results by TraceWin [2].

Table 1: required parameters before the RFQ

Parameters	Numbers	Units
Energy	35	KeV
Current	20	mA
Repetition frequency	50	Hz
Pulse width	CW	-
Twiss parameter α	1.21	-
Twiss parameter β	0.0479	mm/π.mrad

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$\epsilon(nRMS)$	<0.2	π.mm.mrad
Proton fraction	>95	%

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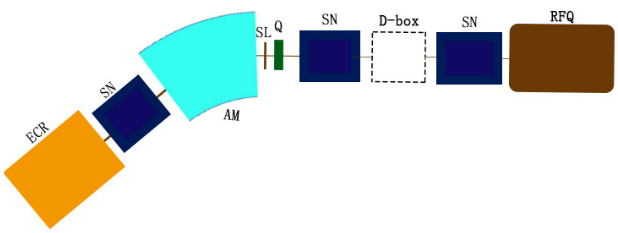

Figure 2: The layout of the LEBT.

SIMULATION RESULTS

Figure 2 shows the layout of the new conceptual designed LEBT. In this construction, the whole length of the LEBT is 2.714m from the source to RFQ entrance. The beam coming from the ion source dose not just consist of proton ion only. In the simulation, 10mA (62.5%) H^+, 5.2mA (32.5%) H_2^+ and 0.8mA (5%) H_3^+ was used to simulate the hybrid beam respectively of the total beam. Typical values of the initial parameters from the ion source are listed in Table 2. In order to prevent the unwanted species from transporting to downstream, the bending magnet will work as the separator. Figure 3 shows the simulation results with analysis magnet or not when the beam passes through three solenoids.

Table 2: required parameters before the RFQ

Twiss Parameters	Numbers	Units
$\alpha x = \alpha y$	-1.865	-
$\beta x = \beta y$	0.1835	mm/π.mrad
$\epsilon(nRMS)$	0.1885	π.mm.mrad

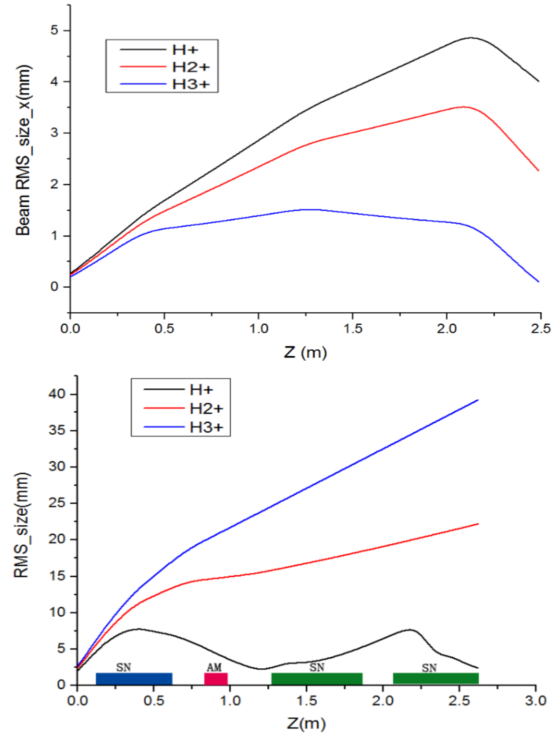

Figure 3: Comparison of the evolution of the beam profile along the LEBT with analysis magnet (the upper one without analysis magnet, the below one one with it).

As to the aperture studies, it can be seen from the Figure 3 that an aperture of radius 8mm slit is sufficient for full transmission of the H^+ beam. Hybrid ions can be eliminated in horizontal axis. In the figure 4 shows the simulation results about the beam scrapped in the LEBT. The unwanted ions about H_2^+ and H_3^+ all lost in the LEBT. Drifts have been chosen to be able to accommodate beam diagnostics, steers, gate valves, vacuum pumps.

The transfer matrix of the charged particle between the beginning of the bending magnet and the export are defined by the following linear model:

$$M_{sector} = \begin{pmatrix} \mathrm{Cos}[K_x\Delta s] & \frac{\mathrm{Sin}[K_x\Delta s]}{K_x} & 0 & 0 \\ -K_x\mathrm{Sin}[K_x\Delta s] & \mathrm{Cos}[K_x\Delta s] & 0 & 0 \\ 0 & 0 & \mathrm{Cos}[K_y\Delta s] & \frac{\mathrm{Sin}[K_y\Delta s]}{K_y} \\ 0 & 0 & -K_y\mathrm{Sin}[K_y\Delta s] & \mathrm{Cos}[K_y\Delta s] \end{pmatrix};$$

Where: $h = \frac{1}{\rho}\frac{\Delta\alpha}{\Delta\alpha}$, $K_x = \sqrt{(1-n)h^2}$, $K_y = \sqrt{nh^2}$, $\Delta s = \rho\Delta\alpha$. this are the bending magnet parameters.

The edge angle matrix is defined by the following linear model:

$$R_{edge} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ \frac{\mathrm{Tan}[\beta]}{|\rho|} & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & \frac{-\mathrm{Tan}[\beta-\psi]}{|\rho|} & 1 \end{pmatrix};$$

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$$\psi = K_1 \frac{g}{|\rho|} \left(\frac{1+\mathrm{Sin}^2[\beta]}{\mathrm{Cos}[\beta]}\right) . \left(1 - K_1 K_2 \frac{g}{|\rho|} \mathrm{Tan}[\beta]\right);$$

The upper formula is the fringe-field correction.

In order to achieve the beam symmetry both in X and Y axis, the bending magnet is designed with a little angle about 20° and a 6°rotation angles at the bending magnet edge. A quadrupole installed behind the bending magnet is used to match the asymmetry action in Y direction.

The combinatorial matrix consisting of the edge angle, rotation angle, drift matrix and quadruple matrix are the following results:

$$R_{comb} = \begin{pmatrix} 0.89749 & 0.62389 & 0 & 0 \\ -0.27677 & 0.92181 & 0 & 0 \\ 0 & 0 & 0.91240 & 0.63096 \\ 0 & 0 & -0.24082 & 0.92946 \end{pmatrix};$$

This combinatorial matrix meets enough accuracy for the symmetry requirement. This configuration of the LEBT was used in the simulations.

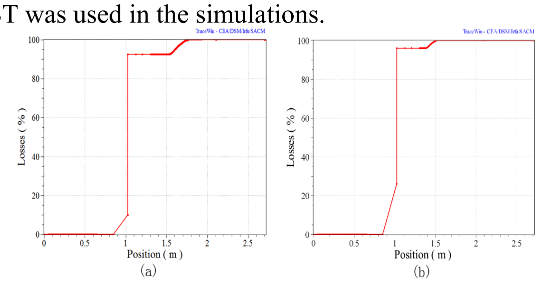

Figure 4: Comparison of the evolution of the beam profile along the LEBT with the slit, (a) shows the H_2^+ ion losses and (b) shows the H_3^+ ion losses.

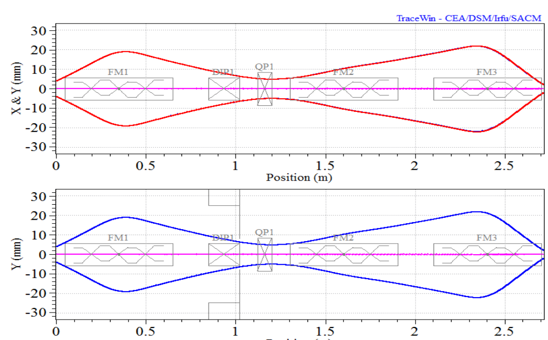

Figure 5: Beam trajectory in LEBT as calculated from partarn envelope calculation in TraceWin.

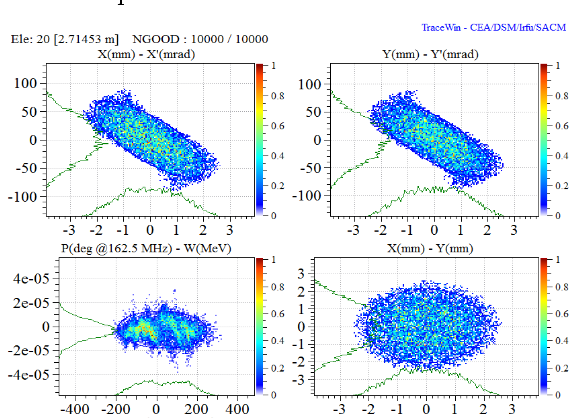

Figure 6: Beam phase spaces in LEBT at the end of the LEBT with 4D ellipse input distribution type.

Table 3: Twiss parameters out of LEBT

Twiss Parameters	Numbers	Units
αx	1.1425	-
αy	1.1408	-
βx	0.0474	mm/π.mrad
βy	0.0476	mm/π.mrad
$\epsilon(nRMS)$xx	0.1968	π.mm.mrad
$\epsilon(nRMS)$yy	0.1992	π.mm.mrad

In the figure 5, it can see that with the 6° rotation angle and quadrupole modulation, the beam trajectory both in X and Y axis is symmetry. Figure 6 shows the beam phase spaces distribution at the end of the LEBT, and the Twiss parameters shows in the table 3. It was found that the simulation results meet the requirements.

SUMMARY AND CONCLUSIONS

A bending-magnet based with three-solenoids LEBT has been designed for C-ADS accelerator at IMPCAS. The main design criterion is to match the beam from ECR ion source to the RFQ without hybrid ions and less H_2 tracing through the RFQ to the downstream. The detailed hybrid ions scrapped and beam dynamic simulation shows in the section 3. The 2.714m LEBT designed with bending magnet will also do well in machine protection system. Faraday cup and Chopper will be considered to be installed behind the first solenoid. With the bending magnet the beam can be cut freely and safely. Furthermore, the H_2 migration will be simulated with VSim code later to observe the residual gas trace into the RFQ and interaction with the beam for space charge compensation.

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