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BEAM PARAMETER RECONSTRUCTION AT THE INPUT OF LEBT OF C-ADS INJECTOR II*

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Abstract

The Injector II for the C-ADS is designed to accelerate a proton beam to 10 MeV in continuous wave (CW) mode with beam current up to 10 mA, which is the demonstration of the key technologies for CiADS. The LEBT section physical length and dynamic lattice is calibrated recently, and the more receivable beam parameters has been reconstructed at the input of LEBT. AS the transport of high current beams at low energies is critical, for at kinetic energies of a few MeV, the beams are space charge dominated. This paper will introduce beam parameters reconstruction based on emittance measurement experiment and PIC code TraceWin to reconstruct with space charge considered.

INTRODUCTION

A project named China Accelerator Driven Sub-Critical System (C-ADS) has been proposed to treat the spent nuclear fuel and began construction since 2011 [1]. Under six years commissioning, the demo facility had accelerated 12.6 mA Pulse proton beam to 26.06 MeV, 170 uA CW proton beam had accelerated up to 25 MeV, and recently the project of C-ADS demo facility just has completed the acceptance. The layout of the demo facility is shown in Figure 1.

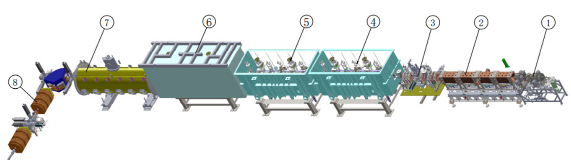

Figure 1: The layout of the demo facility of C-ADS. ① LEBT section ② RFQ ③ MEBT section ④ CM1(HWR010) ⑤ CM2(HWR010) ⑥ CM3(Taper HWR015) ⑦ CM4 (Spoke021) ⑧ HEBT section

The LEBT is designed by Y.Yao [2], the Layout of the LEBT is shown in Figure 2. As the project tasks arranged so compact, the beam parameters had not measured so clear at the beginning of the LEBT commissioning. The LEBT beam parameters of injector II are copied by injector I at IHEP, for the two LEBT designed all by IMP is very similar.

The LEBT physical length has been alignment recently by machinery group, but the collimation error is far away from the dynamic length. Using the initial beam parameters and the actual solenoid magnetic field values for beam transport simulation and tracking, the beam parameters at the end of the LEBT cannot match well with the download section (RFQ). Figure 3 is the beam phase space out of RFQ tracking by matched beam. But for the mismatched beam the transmission of the RFQ is about 98%, and the beam emittance growth is almost 47%. Table1 shows the comparison of these.

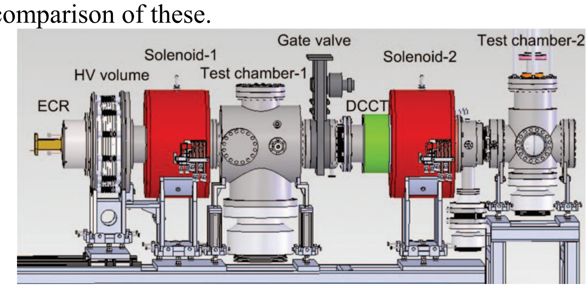

Figure 2: The layout of the LEBT of C-ADS.

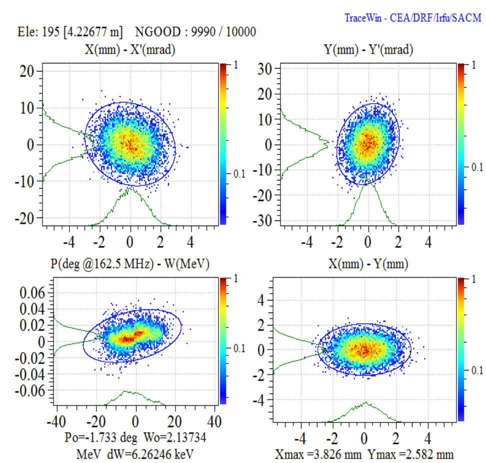

Figure 3: Phase space out of the RFQ.

For getting the real beam initial parameter at the LEBT input, a beam dynamic code named TraceWin combined with python is used for beam parameter reconstruction.

Table 1:Comprision of the Match or Mismatch Beam Parameters out of RFQ

	α x	β x	Ex (RMS)	α y	β y	Ey (RMS)
LEBT Input	0	0.16	0.189	0	0.16	0.189
Matched beam	0.1551	0.2646	0.2257	-0.1945	0.1316	0.2229
Mismatched beam	0.1554	0.2574	0.2916	-0.2294	0.1312	0.2767

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ARITHMETIC FOR RECONSTRUCTION

To get the initial beam parameter at the input of the LEBT, the code named TraceWin is used for reconstruction. This code is based on PIC arithmetic for low energy section beam space charge simulation. By using python calls TraceWin, it can be used for scanning the entrance beam Twiss parameters map and comparing the tracked results at the end of the LEBT with the RFQ matched input parameters to get the target LEBT input parameters.

Oscillation of the beam projections will be added when the injected beam ellipse is not match with the focusing elements. The conception of beam mismatch factor is proposed [3] to describe the quality of the beam matching results. At different location, the Courant-Snyder ellipse parameters α, β, γ defined for represent the beam space phase.

Suppose the matched beam ellipse is defined by

$$\gamma_m x + 2\alpha_m x x' + \beta_m x'^2 = \varepsilon$$

And the mismatched beam ellipse is defined by

$$\gamma x + 2\alpha x x' + \beta x'^2 = \varepsilon$$

Then the mismatch factor is defined by

$$\mathrm{M} = \left[1 + \frac{\mathrm{H} + \sqrt{\mathrm{H}(\mathrm{H}+4)}}{2}\right]^{1/2} - 1$$

Where

$$\mathrm{H} = (\Delta\alpha)^2 - \Delta\beta\,\Delta\gamma$$

And $\Delta\alpha = \alpha - \alpha_m$, $\Delta\beta = \beta - \beta_m$, $\Delta\gamma = \gamma - \gamma_m$.

Different like actual beam matrix σ_m

$$\sigma_m = \begin{bmatrix} \beta_m & -\alpha_m \\ -\alpha_m & \gamma_m \end{bmatrix}$$

Where the $\Delta\sigma$ is useful to express as

$$\mathrm{H} = \Delta\sigma = \begin{bmatrix} \Delta\beta & -\Delta\alpha \\ -\Delta\alpha & \Delta\gamma \end{bmatrix}$$

Mismatch factor M is used for comparing the track beam by TraceWin and the matched initial beam parameter input of the RFQ system. By searching the beam Twiss parameter map input of the LEBT, the more reasonable value can be found.

This beam track by PIC code TraceWin considered with the space charge compensation effect, the SCC. factor is defined as 0.87[4].

The RFQ input matched beam parameters are shown in Table 2.

Table 2: Required Parameters before the RFQ

Parameters	Numbers	Units
Energy	35	KeV
Current	15	mA
Pulse width	CW	-
Twiss parameter α	1.21	-
Twiss parameter β	0.0479	mm/π.mrad
$\epsilon(nRMS)$	<0.2	π.mm.mrad
Proton fraction	>95	%

EXPERIMENT AND SIMULATION

As it is described in the introduction, the physical length of the LEBT had been calibrated recently, the layout of the LEBT mechanical drawings is shown in Figure4.

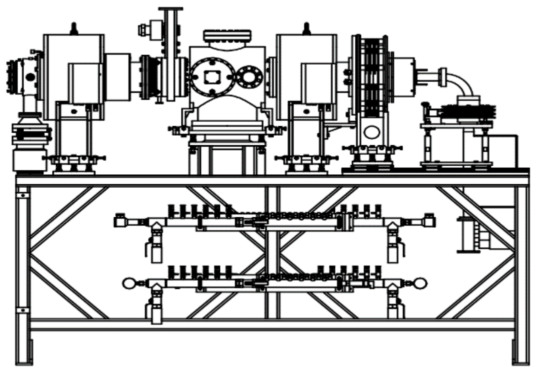

Figure 4: The layout of the LEBT mechanical drawings.

Some experiment has been done for studying the match between LEBT and RFQ. During the experiment, it has shown that the mismatch will lead the beam emittance growth during transport though the RFQ accelerator [5]. The results are shown in Figure 5. (Five group of different solenoids of G2 had be set for studying, but some mistake happened during the Last group G2=280A.)

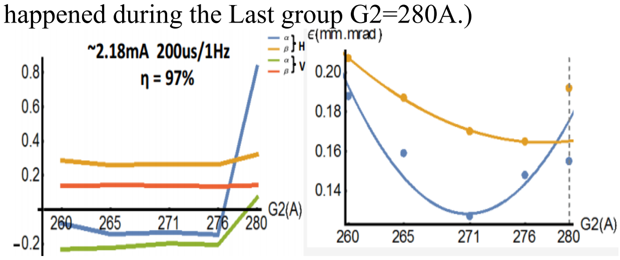

Figure 5: LEBT and RFQ match research.

During the study, the G1 is set as 215A, the beam is about 5mA. From the figure 4, it is still seen that the G1 = 215A, G2 =275A (G1=1980Gs, G2=2533Gs) is the match point of the LEBT and RFQ.

After calibration of the dynamic lattice length, the results of beam track though the LEBT is shown in table 3. For dynamic simulation, the solenoid field map is used, so the length of it is more than the real length. As the results, the input location of the LEBT is almost nearby the extraction electron, the initial beam parameter used previously at the input of LEBT may not too reasonable.

Table 3: Beam Parameters out of LEBT and RFQ

	α x	β x	Ex (RMS)	α y	β y	Ey (RMS)
LEBT Input	0	0.16	0.189	0	0.16	0.189
Out of LEBT	0.261	0.038	0.207	0.259	0.038	0.209
Out of RFQ	0.191	0.259	0.288	-0.198	0.133	0.283

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During the scanning of the input beam parameters of the LEBT, G1=1980Gs G2=2533Gs is chosen as the fixed value for reconstruction. The step length of the Twiss parameters input of the LEBT is about 0.01for both horizontal and vertical of the beam. Figure 6 shows the beam parameters out of the LEBT.

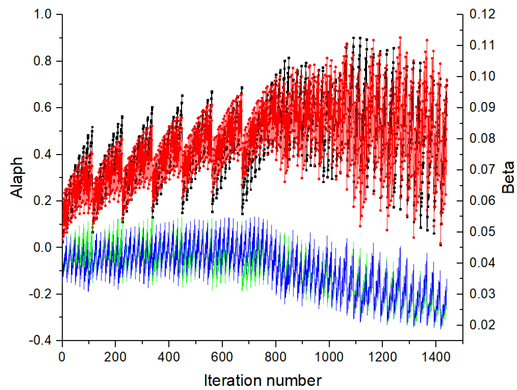

Figure 6: Beam parameters out of the LEBT. (the red for β_x, black for β_y, blue for α_x, green for α_y)

The minimum value of the sum of mismatch factor both in the horizontal and vertical indicates the best match point of the LEBT and RFQ. Figure 7 shows the scaning results.

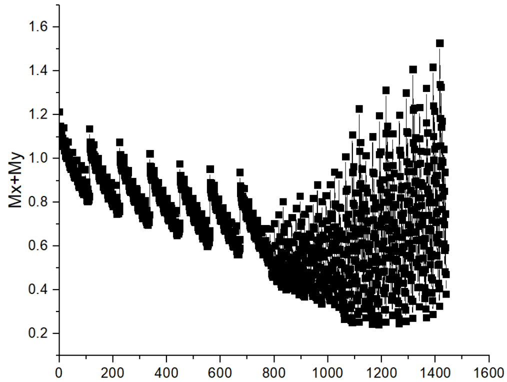

Figure 7: The sum of mismatch factor both of horizontal and vertical direction.

Finally, sorting the simulation results of the mismatch factor at the cross section of the LEBT and RFQ, the minimum data of the sequence corresponding to the input beam parameters of the LEBT is the scanning solution.

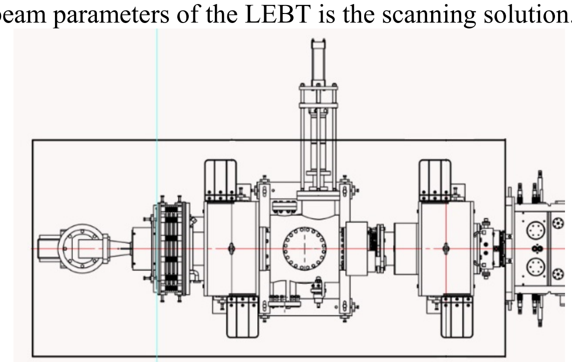

Figure 8: The flat view of the LEBT.

The scanning results of the initial beam parameters at the LEBT input section is shown in Table 4 and the sum mismatch factor is 0.199, beam tracking results at the RFQ input section is shown in Table 5.

Table 4: Initial Beam Parameters at Input of LEBT

	α x	β x	α y	β y
Twiss parameters	1.0	0.24	1.0	0.24

Table 5: Beam Tracking Results out of LEBT

	α x	β x	α y	β y
Twiss parameters	0.916	0.0476	0.979	0.0490

SUMMARY AND CONCLUSIONS

In Figure 8 the blue line shows the real input location of the LEBT. This section nearby the extraction electron of the ion source. Comparing with the simulation results of the beam parameters map scanning, it is more reasonable to accept the initial input parameters at the LEBT entrance.

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