CIADS NORMAL TEMPERATURE FRONT-END DESIGN*

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Abstract

The design and construction with several tens of megawatts superconducting accelerator is the developing direction in the further. The superconducting section follows with the RFQ and MEBT, which needs good enough beam quality. The normal temperature front ends are redesigned for China Initiative Accelerator-Driven Subcritical System (CIADS). The LEBT transports a 35 keV, 10 mA DC proton beam to the RFQ, after the RFQ acceleration the MEBT transports a 2.1 MeV 10 mA CW proton beam to the superconducting DTL. The "Point Source" is proposed in the beam scrape application during the LEBT section to get the ideal transverse beam parameters. To get the ideal longitudinal beam parameters, the new RFQ is designed with little emittance. Collimators are installed in the new MEBT to scrape the outer sphere beams which may turn to halo. Details of the beam dynamics simulations will be given.

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 three years commissioning, the demo facility had accelerated 10 mA CW proton beam to 2.56 MeV, 2.7 mA CW proton beam had accelerated up to 5.17 MeV, and recently the 10 mA, 10 MeV CW proton beam is under commissioning.

The layout of the demo facility is shown in Fig. 1. As the proton beam out of the ECR ion source coupled with H_2^+ and H_3^+, which are the unwanted particles and will be lost in the downstream. Also, another question is the H_2 removal from the ion source to the RFQ and even to the downstream superconducting cavity. After long-time operation with residual gas RFQ performance may decline has reported by SNS and SARAF [2, 3]. For high power accelerator, the beam loss must be controlled in low order, this paper presents the detailed description about a new structure LEBT for eliminate the unwanted particles and how to decrease the transverse and longitudinal emittance in CIADS normal temperature front end.

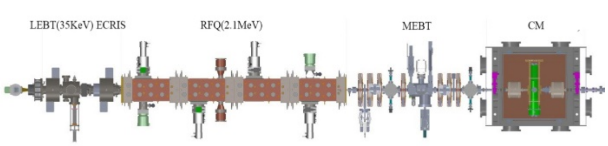

Figure 1: The layout of the ADS LEBT and parts of RFQ.

LEBT SYSTEM

The 10 mA proton DC beam with the energy of 35 keV is extracted from a 2.45 GHz ECR ion source, after the LEBT transmission, match to the RFQ accelerator. 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 meet the proton fraction requirement, a bending magnet and collimator have been considered to substantially reduce the contaminants, such as H_2^+ and H_3^+ [4]. In the previous design, the bending magnet rotation angle and edge angle is chosen with 20° and 6°. It can match well for the symmetry requirement both in X and Y positon. Typical values of the initial parameters from the ion source are listed in Table 2. The space charge compensation is about 0.87 at the vacuum of 1.3E-3 Pa, all these beam parameters refer to the C-ADS accelerator commissioning experience. Figure 2 shows the CIADS LEBT layout.

Solenoids are effective for focusing the low energy beam, especially in LEBT section, but the beam quality decreases with the emittance growth, which contributed by the spherical aberration of the solenoid lens [5]. A "point source" concept is proposed in CIADS LEBT design, which means the beam out of the ion source follows the linear transmission approximation. An aperture is install just after the ion source and before the first solenoid to scrape off the outer parts of the beam particles. This concept is simulated with the initial beam particles generated randomly in 4-dimensional ellipse with Gaussian distribution. The model considered with the space charge effect, the simulation results are shown in Fig. 3.

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	c	-
Twiss parameter β	0.0479	mm/π.mrad
$\epsilon(nRMS)$	<0.2	π.mm.mrad
Proton fraction	>95	%

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Table 2: Typical 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

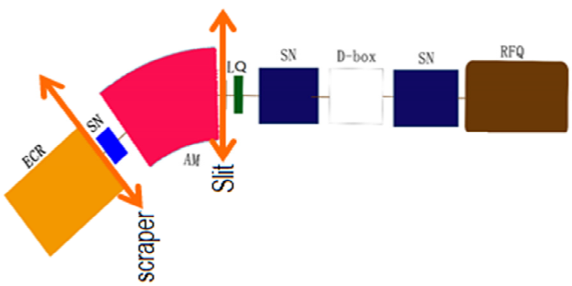

Figure 2: CIADS LEBT layout.

Analysis the beam action in the phase space and real space, it is easy to find that the outer particles are stroked off from the initial beam just by one aperture, which are the parts of the beam with relatively large beta and alpha. The space charge effect also contributes to the beam evolution, but the point source concept is still effective.

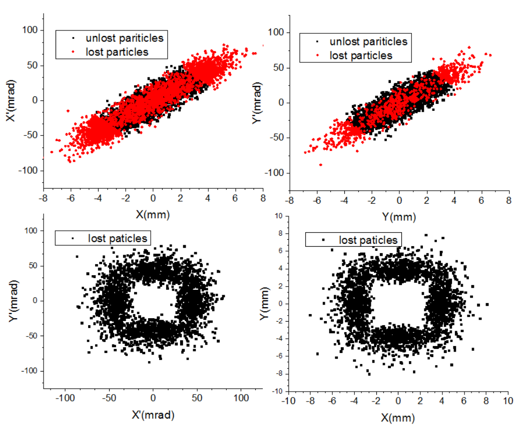

Figure 3: Point source simulation.

The beam transmission is simulated by the TraceWin code. Figure 4 shows the beam envelope of the LEBT, and the space phase at the end of the LEBT is compared between with aperture or not using the same Lattice. The beam particles are scraped off about 21%. Beam parameters is list in the Table 3. Scraping the outer beam particles, the beam will decrease the probability to feel the nonlinear field in the solenoid.

Finally, by using this aperture before the solenoid, it is effective to scrape the "tails" in the phase space and get a good beam quality.

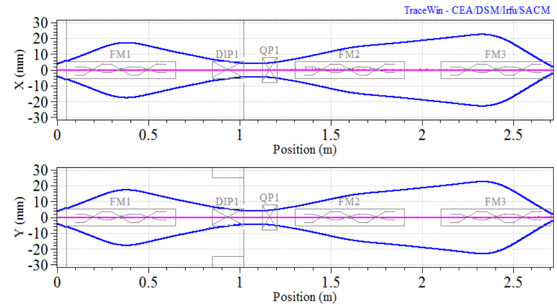

Figure 4: LEBT beam envelope with 3RMS.

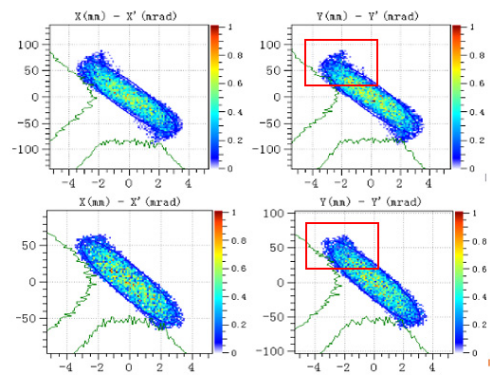

Figure 5: Compare between the phase space with (upper) or without aperture (down).

Table 3: Beam Parameters

Twiss Parameters	Without aperture	With aperture
α_x	1.2025	1.2010
$\beta x(mm/pi.mrad)$	0.0474	0.0476
α_y	1.2008	1.2186
$\beta y(mm/pi.mrad)$	0.0476	0.0482
$\boldsymbol{\varepsilon_x}$	0.1968	0.1729
$\boldsymbol{\varepsilon_y}$	0.1922	0.1729

RFQ SYSTEM

The RFQ for C-ADS injector II was designed by collaboration between LBNL and IMP. Table 4 shows the RFQ design parameters based on our demands. The ratio between maximum emittance and RMS emittance is about 45, and it still meets C-ADS injector II requirements. In the process of demo facility conditioning, this RFQ operation status is very good. The CW beam operation is more than 200 hours. But for the CIADS which is a high power machine, a good longitudinal beam quality is critical for the downstream SC section. The beam loss may occur because of the large longitudinal emittance. According to our present understanding, the maximum longitudinal emittance is the main issue which needs to be considered. Based on the above consideration, some beam dynamics design and simulation were done to study this question. Compared with the existing RFQ parameters, the new beam dynamics scheme has preliminarily achieved a smaller total longitudinal emittance.

Table 4: Compare Between Injector II and CIADS RFQ

Parameters	Injector II	CIADS
Inter-vane Voltage(kV)	**65**	**70**
KP factor	1.2	1.32
Min.aperture (mm)	3.2	3.33
Modulation	1-2.38	1-2.19
Syn.Phase (deg)	-90 ~ -22.7	-90 ~ -25
Long.Emittance _rms (keV ns)	**0.0534**	**0.0506**
Long.Emittance _max (keV ns)	**2.4267**	**1.9156**
Proton fraction	>95	100
Lcavity/Lelectrode (cm)	**420.8/419.2**	**450**
Transmission	99.6	99.4
Cell number	192	247

MEBT SYSTEM

The main function of the MEBT is to match the beam from RFQ to Superconducting (SC) Half Wave Resonator (HWR) sections with emittance preservation; the CIADS MEBT has been designed to be mechanically compact. For CIADS the MEBT section contains three triplets, three bunchers and also a bending magnet. The triplets are used for transverse beam focus and match with the downstream elements. More bunchers at -90° can provide stronger longitudinal focus before the superconducting section, which will decrease the superconducting focus pressure and increase the acceleration gradient compared with C-ADS MEBT [6]. A new bending magnet is installed in the MEBT for online measurement the beam energy dispersion out of the RFQ. Figure 6 shows the CIADS MEBT layout. Figure 7 shows the MEBT beam envelope to the downstream and though the bending magnet to the Faraday cup, and Table 5 lists the Twiss parameters before and after MEBT.

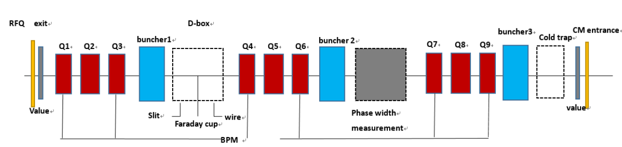

Figure 6: CIADS MEBT layout.

As seen from the simulation, bunching cavity positions are optimized with small envelopes both transversely (≤8 mm, 3RMS) to deduce RF defocusing and longitudinally (≤40°) to minimize longitudinal emittance growth.

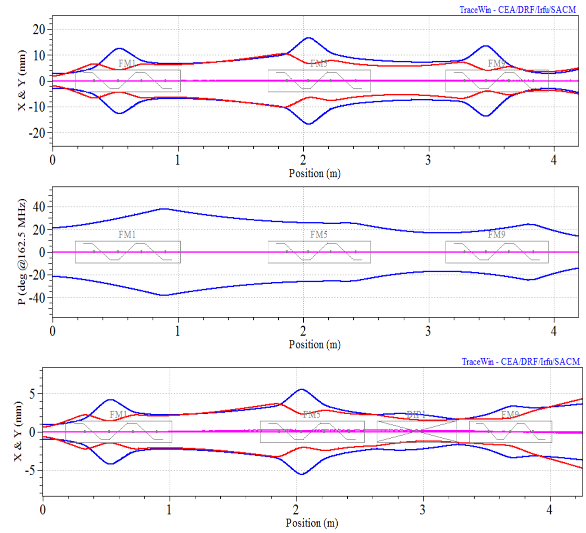

Figure 7: MEBT beam envelope with 3RMS to the downstream (upper) and through the bending magnet to the Faraday cup (lower).

Table 5: TWISS paremeters before and after MEBT

Twiss Parameters	RFQ exit	SC entrance
α_x	0.3	-0.58
$\beta x(mm/pi.mrad)$	0.25	0.57
α_y	-0.11	-0.58
$\beta y(mm/pi.mrad)$	0.11	0.57

One of the other important roles the MEBT taking part in is the beam diagnostics. The more transverse emittance measurement and longitudinal beam phase width measurement is accurate; the better beam performance is understood. Reference with the C-ADS injector II，the new MEBT will also installed with wire and slit to measure the transverse emittance, and at the end of the MEBT ICT and FCTs will install for beam phase width. The bending structure will use to check the RFQ energy desperation.

SUMMARY AND CONCLUSIONS

CIADS project is a strategic plan to solve the nuclear waste problem and the resource problem for nuclear power plants in China. The linac will accelerate 10mA proton beam from 35keV out of ECR ion source to 600MeV. For CIADS driven linac, which is a 6 MW machine, the most critical issue is the beam loss control. The RT section producing good beam performance for SC section is beneficial for beam loss control. LEBT and RFQ will respectively be used to provide good quality beam in transverse and longitudinal. And though the simulation, the point source conception is useful, and the new RFQ design is also meaningful for CIADS linac beam loss control.

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