CIADS HEBT LATTICE DESIGN*

Y. S. Qin†, W. L. Chen, Y. He, H. Jia, S. H. Liu, Z. J. Wang
Institute of Modern Physics (IMP), Chinese Academy of Sciences, Lanzhou, China

Abstract

CIADS (China Initiative Accelerator Driven System) 600MeV HEBT (High-Energy Beam Transport) will deliver 6 MW beam to the target, with CW (continuous wave) 10 mA beam. The most serious challenges are vacuum differential section and beam uniformization on the target. A novel collimation plus vacuum differential section is proposed in the lattice design. A scanning method is designed for the round beam uniformization on the target.

INTRODUCTION

As a SC LINAC, CIADS will be operated in superconducting temperature (2 K) as shown in Figure 1 [1]. HEBT will transport beam to the target stably and realize the beam-target coupling.

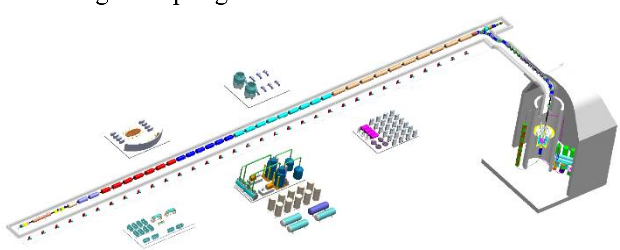

Figure 1: Layout of CIADS.

Because of the high power, we use collimation system to minimize the uncontrolled beam loss along the beam line, especially at the holes of the vacuum differential section. To decrease the risk of target melting, peak power density (PPD) needs to be minimized. The target is granular flow target [2]. The parameters of the HEBT is shown in table 1 as below.

Table 1: HEBT Parameters

Parameter	Value	Unit
Particle	proton	—
Energy	600	MeV
Current	10	mA
Duty factor	100	%
Normalized rms emittance (x/y/z)	0.28/0.28/0.33	π mm.mrad
Input αx/αy/αz	1/1/-1	—
Input βx/βy/βz	20/20/20	mm/π.mrad
Target shape	round	—
FWHM of beam on the target	160	mm

* Supported by National Natural Science Foundation of China (11525523)
† E-mail: marshal@impcas.ac.cn

CONSIDERATION

To decrease beam power loss along the beam line, collimation system is considered. Cross-over lattice is designed to form a small beam waist before the target, where to set the first differential hole and act as the shielding of neutron reflection from the target to protect the accelerator.

The property of the granular flow target leads to three considerations:

1. Vacuum transition

Helium is designed to be heat exchanger and lubrication gas between metallic balls of the granular target [2]. The vacuum degree needs to be kept at 0.5 atm level, while it is 10^{-7} Pa in the SC cavity. This means HEBT should realize vacuum transition about 11 orders of magnitude. Vacuum differential system is adopted in the design.

2. Power density uniformity on the target

To decrease the risk of target melting, the maximum temperature rise of balls should be considered, the same goes for PPD accordingly. The minimum falling speed of the metallic balls and the size of the target depends on PPD, which is the motivation of power density uniformity on the target.

We choose scanning method to decrease PPD on the target. Unlike high-order magnets, scanning method doesn't rely on the beam position or distribution that much, especially when considering beam halo.

3. Beam shape on the target after scanning

To increase effective area, the target surface is designed to be round rather than rectangle or square, which requires uniform distribution in a circular area with diameter 160 mm after scanning.

Simulation shows that when falling down, balls near the center are pressed because of the radial velocity of other balls, which may lead to lower falling speed. A scanning method need to be introduced to balance the situation mentioned above. The distribution should be "hollow" after scanning.

LATTICE DETAILED DESIGN

Considering the function of HEBT, detailed design consists of 4 section: Bending section, Beam collimation section, Vacuum differential section and A2T (Accelerator to Target). Figure 2 shows 10 RMS envelope of the whole HEBT line. There're matching sections between the 4 sections, such that transversal Twiss parameters would match.

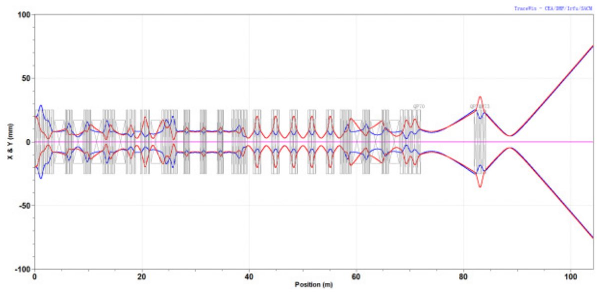

Figure 2: 10 RMS envelop.

Bending Section

Bending section is an achromatic design to avoid beam envelope increase in non-deflection section because of dp/p and dispersion. Figure 3 shows the dispersion function in horizontal and vertical plane.

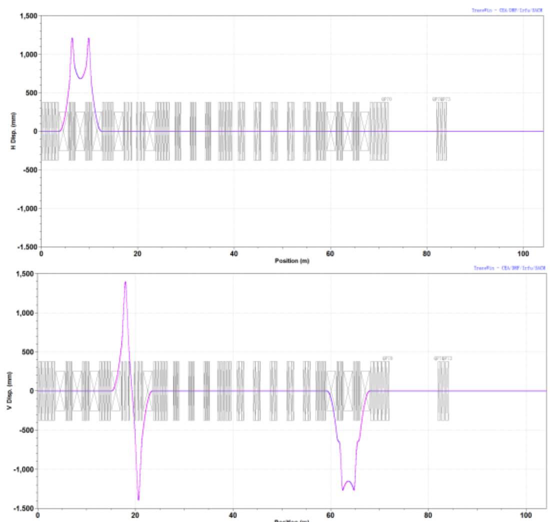

Figure 3: Bending section with achromatic design. (up: horizontal dispersion, down: vertical direction)

Beam Collimation Section

In transverse beam collimation section, periodic collimators are set with 60° phase advance in both horizontal and vertical direction. The collimator aperture is chosen as 7 rms beam envelope such that power loss on the collimator would be less than 2 kW even if considering errors of accelerator [3]. Triplet is introduced to realize periodic phase advance. Figure 4 shows the envelope in beam collimation section. Beam halos are scraped off after 3 collimators as shown in Figure 5.

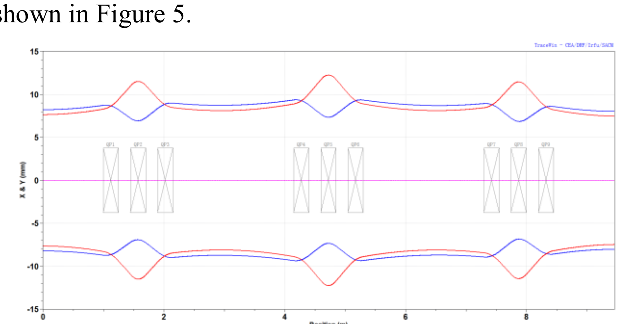

Figure 4: Beam collimation section with 10 RMS envelope.

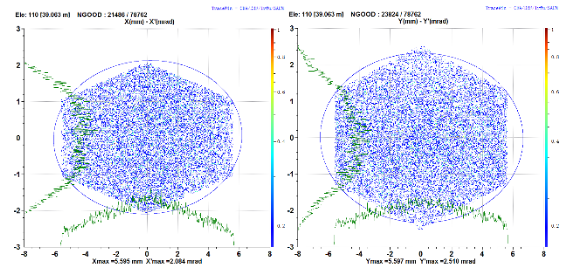

Figure 5: Phase space after transversal collimation.

In longitudinal beam collimation, we choose the collimator position at the first dispersion section where the dispersion function begins to increase sharply. Particles with large momentum dispersion will lose at longitudinal collimator rather than other dispersion section downstream.

Vacuum Differential Section

6 holes with diameter of 10 mm are designed in vacuum differential section. The envelope of vacuum differential section is shown in Figure 6.

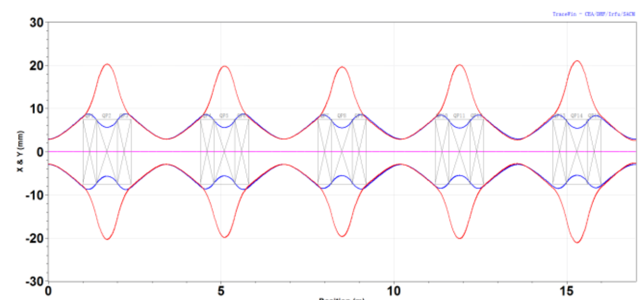

Figure 6: 10 RMS envelope of vacuum differential section.

There should be no power loss on the holes. Figure 7 shows that the emittance after collimation is well inside the acceptance of the vacuum differential section. There would be no loss at the differential holes.

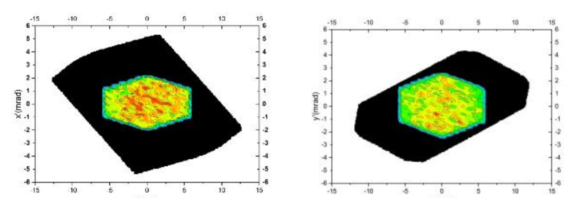

Figure 7: Emittance and acceptance.

A2T

Considering the requirement of the target, wobbler scanning method is introduced to realize round beam distribution after scanning, with both angular rotation and radial modulation as shown below

$$\begin{cases} r = f(t) \\ \theta = 2\pi f_{\varphi} t \end{cases} \tag{1}$$

To decrease PPD on the target, uniformity should be considered seriously, which depends on $f(t)$. Calculation and simulation has been done to prove that it would be perfectly uniform after scanning when $f(t) \propto \sqrt{t}$ [4].

ISBN 978-3-95450-169-4

Considering periodicity, the radial modulation would be the function of time shown as below

$$\begin{cases} r = A\cdot\sqrt{2f_r(t-nT)}, nT < t \le (n+\frac{1}{2})T \\ r = A\cdot\sqrt{2f_r(nT+T-t)}, (n+\frac{1}{2})T < t \le (n+1)T \end{cases} \quad (2)$$

where $T = 1/f_r$ is the period of radial modulation.

The parameters for scanning is shown in Table 2.

Table 2: Scanning Parameters

Parameter	Value	Unit
Angular frequency	295	Hz
Radial frequency	115	Hz
Amplitude	80	mm
Beam distribution before scan	Gaussian	—
σ of Gauss distribution	7	mm
Uniformity after scan	99.4	%
PPD on target after scan	49.7	$\mu A/cm^2$

To realize hollow distribution on the target, we made a cut at r=10 mm which is shown in Figure 8.

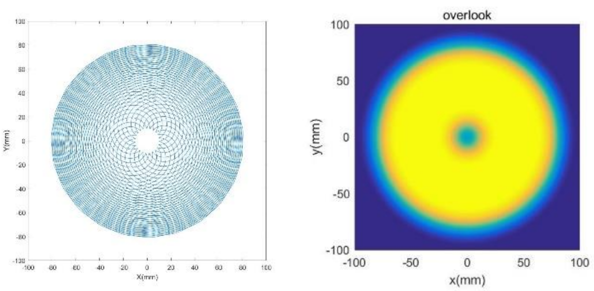

Figure 8: Hollow distribution.
(left: scan path, right: distribution after scanning)

Compared to the situation without scanning, PPD decreased to 1/65 of Gaussian distribution with σ=7 mm. Compared to ESS's result [5], 49.7 $\mu A/cm^2$ is a reasonable value for the tolerance of the target. It is also an accepted value for the granular target.

Cross-over with 180° phase advance is designed to realize the first vacuum difference and neutron shield as shown in Figure 9. What's more, peak magnetic field of scanning magnets would be lower because of the amplifying function of the cross-over [6].

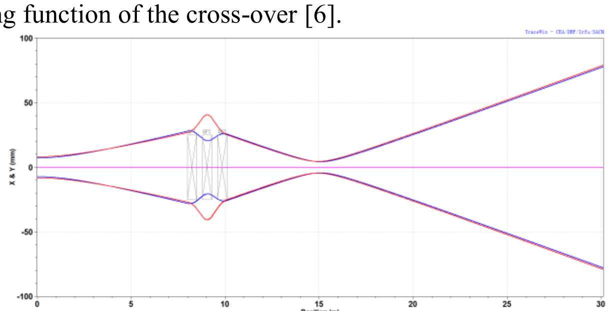

Figure 9: Cross-over with 180° phase advance design.

Multi-particle Simulation

Figure 10 shows beam loss with multi-particle simulation. There's no loss at vacuum differential holes.

Beam loss are controlled at the collimation section.

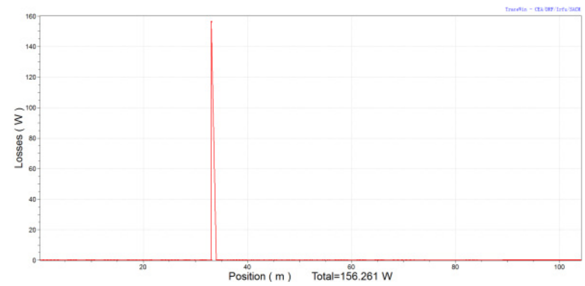

Figure 10: Beam power loss only at collimators.

Figure 11 shows the phase space of the input and output of HEBT.

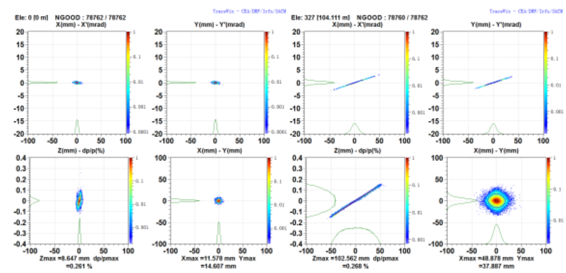

Figure 11: Phase space (left: input, right: output).

SUMMARY

Beam halos are collimated at collimation section with 60° phase advance section. There's no loss at the vacuum differential holes. Uniformity is achieved on the target by scanning magnets and the peak power density is less than 50 $\mu A/cm^2$. Cross-over with 180° phase advance are designed.

The design is a conceptual design and subsequent detailed design will follow.

ACKNOWLEDGEMENT

One of the authors, Huan Jia, would like to thank H.D. Thomsen for useful discussion about A2T design.

REFERENCES

[1] Y. He *et al.*, Scope of CIADS Linear Accelerator, International Review on SRF LINAC of CIADS, Lanzhou, China, 2016.

[2] Lei Yang *et al.*, New concept for ADS spallation target: Gravity-driven dense granular flow target, *Science China Technological Sciences*, Volume 58, Issue 10, 2015.

[3] M.A. Plum *et al.*, in *Proc. PAC'09*, WE6RFP027, 2009, pp.2847-2849.

[4] WANG Xiang-Qi *et al.*, Design of proton beam optics to realize beam distribution transformation in C-ADS HTBT, *Chinese Physics C*, Vol. 37, No. 2, 2013.

[5] H.D. Thomsen *et al.*, in *Proc. IPAC' 14*, 2014, WERPO072, p.2118.

[6] H.D. Thomsen *et al.*, in *Proc. HB' 16*, 2016, WEAM7Y01, p.427.