STUDIES OF TRANSVERSE EMITTANCE GROWTH IN CSNS LINAC DTL*

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Abstract

The transverse emittance at the exit of the China Spallation Neutron Source（CSNS）DTL is measured regularly every year. However, recently, the measured transverse emittance growth became larger than the historical data. It is also bigger than the simulated emittance. The process of measurement, data analysis and matching methods used are almost the same. Several factors contributed to the transverse emittance growth are analysed and presented in this paper. Compared to other factors, longitudinal mismatch contributes the most growth.

INTRODUCTION

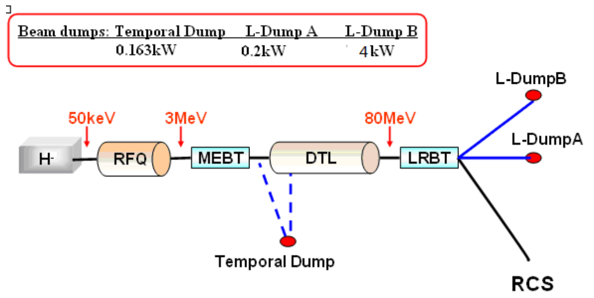

Figure 1: CSNS linac layout.

The CSNS is designed to accelerate proton beam pulse to 1.6GeV at a 25Hz repetition rate while striking a solid metal target to produce spallation neutrons. The accelerator aims to provide 100kW of proton beam power with more than 90% reliability. In 2024, the beam power is increased to 160kW with more than 93% reliability. The accelerator complex consists of an 80MeV H$^-$ linac as the injector and a 1.6GeV rapid cycling proton synchrotron (RCS), as shown in Fig. 1 [1]. The linac consists of a 50keV H- ion source, a 3MeV RFQ, an 80MeV DTL, and several beam transport lines. Table 1 shows the main parameters of the CSNS linac.

The transvers beam emittance at the exit of the DTL is measured regularly. However, this year, the transverse beam emittance increase about 25% compared to the recorded value. In 2021, the horizontal and vertical rms emittance is 0.346 and 0.337 π mm mrad at the beam current of 15mA. For this year, the horizontal and vertical rms emittance is 0.434 and 0.399 π mm mrad at the same current. Although the transverse rms emittance growed about 25%, the activation levels throughout the linac didn't increase. It kept less than 7mrem/hour at 30cm. And the beam profile obtained from the wire scanner measurement at the exit of the DTL also didn't show any significant beam halo, indicating that the beam didn't mismatch seriously.

Table 1: Main Parameters of the CSNS Linac

	Ion Source	RFQ	DTL
Input Energy (MeV)		0.05	3.0
Output Energy (MeV)	0.05	3.0	80
Pulse Current (mA)	20	10	10
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

Several factors contributing to transverse emittance growth are analysed, including mismatch and imcomplete transverse lattice. We also performed beam experiments to slove these issues.

EMITTANCE GROWTH STUDIES

Mismatch

Discrepancies between the physical model and actual machine parameters are common, and these differences can typically be minimized using beam-based calibration methods [2]. The CSNS MEBT consists of ten quadrupoles and two buncheres, which are utilized for longitudinal and transverse matching. The equivalent slicing model method is employed to construct magnet models [3], incorporating the fringing field effect. The amplitude and phase of two bunchers are determined using the phase scan signature method [4]. A pair of FCTs after each buncher is used to measure the beam phase difference during cavity amplitude and phase scanning. By matching the measured beam phase difference to the simulated beam phase differences, the cavity phase and amplitude can be determined. However, as the pair of FCTs is close to the buncher and the voltage of the buncher is small compared to an accelerating cavity, results in insufficient precision of the amplitude calibration. Discrepancies between the amplitude from the matching calculation and the actual RF setting can lead to transverse emittance growth.

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Table 2: Twiss Parameters at the DTL Exit With Different Buncher Amplitudes

	α	**β (mm/pi mrad)**	**ε Norm.rms (pi mm mrad)**
Horizontal			
Nominal	-0.294	2.925	0.468
Modified	-0.316	3.064	0.449
Vertical			
Nominal	-0.929	3.373	0.443
Modified	-0.832	3.349	0.406

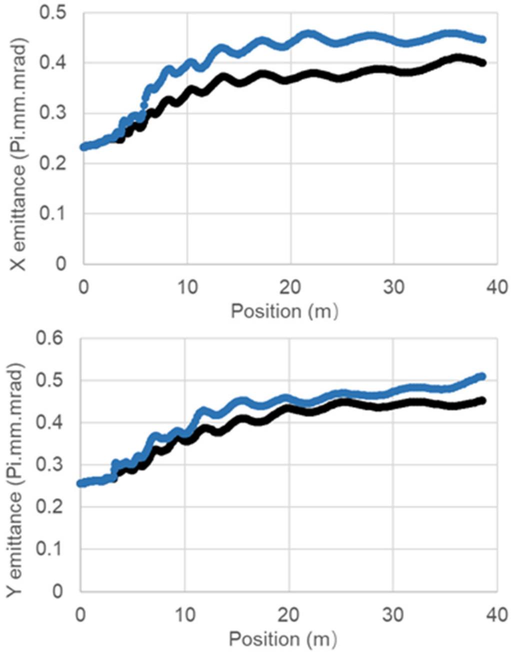

Figure 2: Simulated emittance at the designed buncher amplitudes and the mismatched settings.

Based on the matching calculation, the final amplitude of two bunchers were adjusted to minimize the emittance at the exit of the DTL. Table 2 presents the measured beam twiss parameters and emittance for nominal amplitudes and the modified amplitudes of two bunchers. The results indicate that the horizontal and vertical emittances decreased by approximately 4% and 9% respectively, when the amplitude of the second buncher was reduced to to 80% with respect to the design settings. Figure 2 illustrates the simulated transverse emittance growth using the TraceWin code. The DTL spans from 3.07m to 38.55m. In the simulation, the modified setting correspond to the design amplitudes of bunchers(black), while the nominal settings correspond to the design amplitudes divided by 0.8(blue). The results demonstrate that the transverse emittance increases when the actual used buncher amplitudes exceeds the design amplitude.

We also applied this practical method to modify quadrupoles, but failed. It is hard to find a minimum emittance by only modify one quadrupole. And the beam transmission is sensitive to the changement of the gradients of magnet.

Lattice Modification

Electromagnet quadrupoles are used for transverse focusing in the CSNS DTL. There are a total of 161 quarpoles making up 40 FFDD foucsing periods. The field settings of the quarupoles are calculated using the equipartioning design method [5]. For a space-charge-dominated beam, the beam is equpartitioned when

$$\frac{T_{\perp}}{T_{\parallel}} = \frac{k_x \varepsilon_{nx}}{k_z \varepsilon_{nz}} = 1 \qquad (1)$$

where k_x, k_z are wave numbers, and ε_{nx}, ε_{nz} are nomalized emittances.

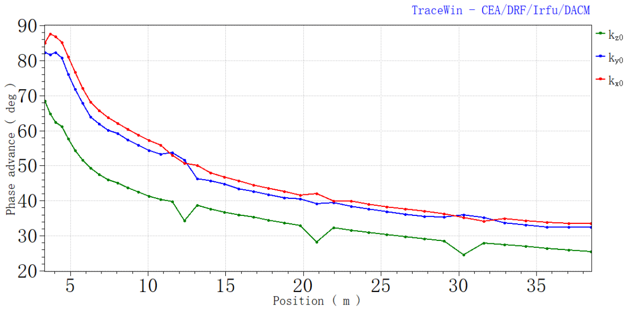

Figure 3: Phase advance per period of the CSNS DTL.

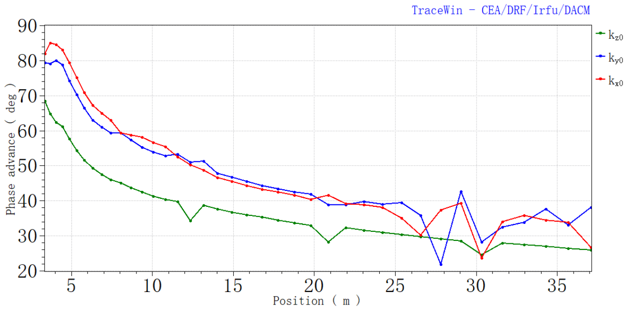

Figure 4: Adjusted phase advance per period.

Table 3: Twiss Parameters at the DTL Exit With Different Phase Advance

	α	**β (mm/pi mrad)**	**ε Norm.rms (pi mm mrad)**
Horizontal			
Nominal	-0.161	4.899	0.434
Adjusted	-0.316	3.064	0.449
Vertical			
Nominal	-0.827	3.176	0.443
Adjusted	-0.832	3.349	0.406

Figure 3 displays the designed longitudinal and transverse phase advance per period of the CSNS DTL. Figure 4 illustrates the actual used phase advance after operating for a long time. Throughout operation, the quadrupole gradients are adjusted to eliminate any hot spots resulting from beam fluctuation and parameter shift. These adjustments can disrupt the continuity of the focusing periods, as depicted in Fig. 4, and potentially lead to emittance growth. Despite efforts to restore the phase advances to their design values, the transverse emittance at the DTL exit didn't decrease as anticipated, as shown in Table 3.

CONCLUSION

In the paper, we investigated several factors contributing to the grow of transverse emittance. Based on the model calculation, we implemented a practical method to reduce longitudinal mismatch. This approach resulted in a reduction of approximately 9% in the transverse emittance at the exit of the DTL. As the measured emittances exceeded the simulated values, more experiments are being planned to address this discrepancy.

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