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SOLUTION TO BEAM TRANSMISSION DECLINE IN THE CSNS LINAC OPERATION USING MEASUREMENTS AND SIMULATIONS*

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Abstract

The China Spallation Neutron Source (CSNS) started operation from 2018 and now run at its design power. However, a problem was observed that the beam transmission of the linac was decreasing and the beam loss was increasing during the operation. With simulations and measurements, we found that a long longitudinal tail existed in the beam bunch output from the RFQ. And this tail caused the longitudinal mismatch in the following linac. After inhibition of the longitudinal tail in the beam bunch, the beam transmission in operation can keep stable.

INTRODUCTION

The layout of the CSNS linac is shown in Fig. 1. It consists of an H^- ion source, a 3 MeV RFQ, an 80 MeV DTL and several beam lines [1]. Table 1 shows the main parameters of the CSNS linac. The commissioning of the linac started from 2015. In January 2018, the last DTL tank has been commissioned and the H^- beam has been accelerated to the design energy of 80 MeV for the first time. The commissioning was performed with the peak current of 10 mA, the pulse width of 100 µs, and the repetition rate of 1 Hz. Figure 2 shows an overlay of Current Transform signals along the linac. After performing orbit correction, transverse matching, and model optimization, the beam transmission of the RFQ can be about 97% and that of the DTL can be about 100% (with 1% uncertainty).

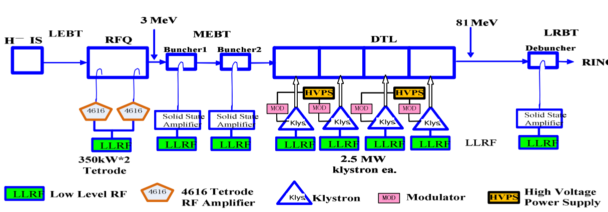

Figure 1: CSNS linac layout.

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	15	15
RF frequency (MHz)		324	324
Chop rate (%)		50	50
Duty factor (%)	1.3	1.05	1.05
Repetition rate (Hz)	25	25	25

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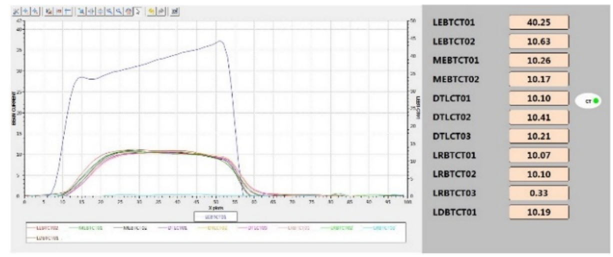

Figure 2: Current Transform signals along the linac.

BEAM TRANSMISSION DECLINE

The CSNS facility started operation in September 2018. Now it runs at its design power 100 kW. However, a problem was observed in the operation. The beam transmission of the DTL might drop about 2~4% in the operation. Firstly, we thought the decline may due to the instability of magnet current or RF filed. After monitoring these parameters for a long time, they were found to be stable, but the transmission decline was still observed. Finally, we found out that the reason to this problem is beam instability from the ion source. The RFQ transmission was affected by the beam instability. And the beam parameters output from the RFQ were changed. As a result, the beam was mismatched while transporting in the DTL and then lost in the DTL. In our experiments, we found the DTL transmission decline was synchronous with the RFQ transmission decline, like showing in Table 2.

Table 2: Measured Beam Transmission of the Linac

	Transmission (%)		
RFQ	83.4	94.04	96.85
DTL	95.88	96.36	98.00

BEAM MISMATCH

The beam mismatch contains two aspects: transverse mismatch and longitudinal mismatch. We will analyse them by using measurements and simulations.

Transverse Mismatch

As shown in Fig. 3, the MEBT is used to match beam output from the RFQ to the DTL. The MEBT includes ten quadrupole magnets (Q1~Q10) for transverse matching, two 324 MHz buncher cavities for longitudinal matching, and various beam diagnostic instrumentation for beam diagnosis [2].

To do matching, it is essential to get the initial beam Twiss parameters output from the RFQ. Two sets of diagnostics are adopted to measure beam Twiss. Firstly, four wire scanners are place in the MEBT to measure beam profile. The beam sizes are calculated from profile data obtained at the measurement stations. Calculating the beam

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Twiss parameters is done using beam sizes and an envelope model. The beam Twiss parameters are found numerically by minimizing the RMS error between the measurements and the model predictions, as shown in Fig. 4. Table 3 shows the comparison of the design values (with PARMTEQM) and the measured values [3]. The Twiss parameters in the horizontal plane are agreed well with the simulated values, while those in the vertical plane are obviously deviated from the simulated values.

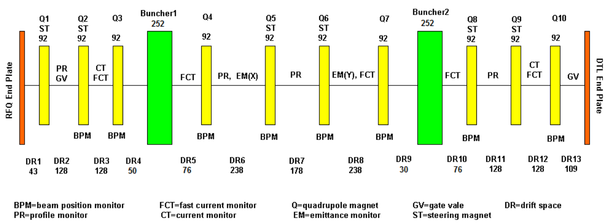

Figure 3: Layout of the CSNS MEBT.

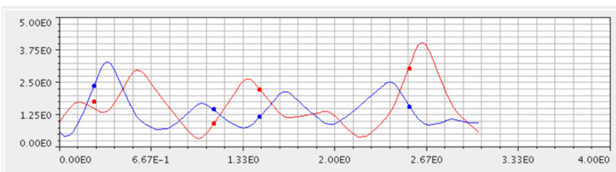

Figure 4: Beam RMS size along the MEBT (Lines represent model predictions, and dots represent measurements with wire scanners).

Table 3: Twiss Parameters at the MEBT Entrance

	α	β (mm/ π mrad)	ε Norm.rms (π mm mrad)
Horizontal			
PARMTEQM	-1.77	0.23	0.22
WS	-1.24	0.18	0.18
Vertical			
PARMTEQM	0.64	0.07	0.21
WS	1.58	0.14	0.15

Secondly, A transverse emittance monitor is installed in the middle of the MEBT. It is double-slit type. The beam Twiss parameters are found by direct statistical calculation, as shown in Fig. 5. The calculated beam Twiss parameters from these two sets of diagnostics can be used to check each other. We used the beam Twiss calculated with wire Scanners as the initial beam, and then simulated it propagating through the MEBT with TraceWin [4]. At the location of the emittance monitor, the simulated beam Twiss parameters were compared with the calculated one with the emittance monitor, as shown in Table 4. The two groups of the beam Twiss are basically agreed except the horizontal emittance.

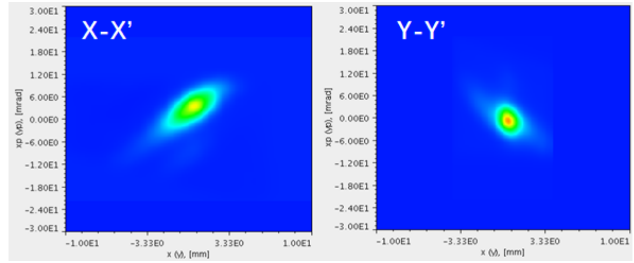

Figure 5: Measured beam emittance at the location of the emittance monitor.

Table 4: Twiss Parameters at the Emittance Monitor

	α	β (mm/ π rad)	ε Norm.rms (π mm mrad)
Horizontal			
TraceWin	-3.89	0.86	0.18
EM	-2.44	0.99	0.11
Vertical			
TraceWin	1.40	0.31	0.16
EM	0.96	0.54	0.16

With different RFQ transmission, several groups of beam Twiss parameters have been measured, as shown in Table 5. It is shown that the beam Twiss parameters change a bit with different RFQ transmissions. Here the beam Twiss parameters measured with the emittance monitor are used because the wire scanner signals are bad when the RFQ transmission is 82%. We use beam Twiss parameters in Table 5 as initial beam parameters, and then simulated beam propagating from the point of the emittance monitor to the end of the DTL. The results shows that the beam loss caused by the transverse mismatch is less than 1%. The transverse mismatch isn't the main reason for the transmission decline in the DTL.

Table 5: Beam Twiss Parameters at the Emittance Monitor with Different RFQ Transmission

RFQ transmission (%)	α	β (mm/ π mrad)	ε Norm.rms (π mm mrad)
Horizontal			
82	3.14	1.30	1.66
92	3.07	1.26	1.45
97	3.61	1.50	1.41
Vertical			
82	1.05	0.52	3.91
92	0.89	0.42	3.01
97	0.98	0.44	3.06

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Longitudinal Mismatch

There will be a longitudinal tail exists in the beam bunch output from the RFQ if the RFQ transmission is low. And particles in the tail will be lost in the DTL because they are out of the longitudinal acceptance, as shown in Fig. 6. Compared to the transverse mismatch, the longitudinal mismatched beam lost more in the following linac.

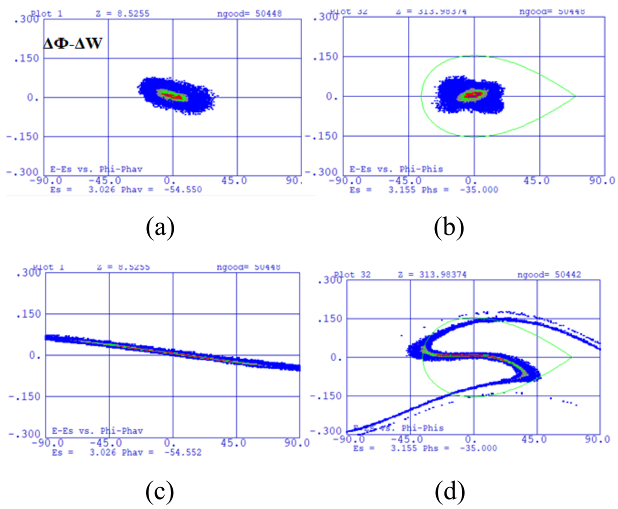

Figure 6: ΔΦ-ΔW phase space plot: (a) Longitudinal matched beam from the RFQ (b) Longitudinal matched beam into the DTL (c) Longitudinal mismatched beam from the RFQ (d) Longitudinal mismatched beam into the DTL.

SOLUTIONS

The beam instability of the Ion Source caused the beam transmission decline in the RFQ and the DTL. However, it is difficult to relate the transmission decline to the ion source at first. Because the beam current almost has no change. Only the beam orbit output from the ion source changes. To solve this problem, many improvements have been made for the ion source. A control closed loop between the exciting current of bending magnet and the variable beam extraction voltage due to the beam current oscillation is also developed to ensure the beam central orbit from ion source unchanged [5]. So, the beam transmission of the linac could keep stable in the operation.

CONCLUSION

The beam transmission of the DTL was found dropping 2~4% in the general operation. The reason to this problem is beam orbit change output from the ion source. The beam orbit change caused a long tail in the beam bunch output from the RFQ. It is the main factor to the beam loss in the following linac. After many improvements have been made for the ion source, the beam transmission could keep stable.

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