BEAM COMMISSIONING RESULTS FOR THE CSNS MEBT AND DTL-1

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Abstract

The China Spallation Neutron Source (CSNS) is designed to deliver a 1.6GeV proton beam to a solid metal target for neutron scattering research. It will be constructed in two phases. In the 1st phase, the beam power is designed to be 100kW. In the 2nd phase, the beam power will be upgraded to 500kW by doubling the linac output energy and beam current. The accelerator complex consists of a 50keV H^- ion source, a 3MeV radio frequency quadrupole (RFQ), an 80MeV drift tube linac (DTL), and a 1.6GeV rapid-cycling synchrotron (RCS). Until March 2016, the front end and the first tank of DTL have been fully commissioned. The primary design goals of peak current, transverse emittance and beam energy have been achieved. This paper reports on the methods and the results of the commissioning.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is located in southeast China. The accelerator complex consists of a 50keV H^- ion source, a 3MeV radio frequency quadrupole (RFQ), an 80MeV drift tube linac (DTL), a 1.6GeV rapid-cycling synchrotron (RCS) and several beam lines [1]. The RF frequency for both RFQ and DTL is 324MHz. Until March 2016, two runs of beam commissioning have been completed. In the 1st run, the front-end has been commissioned and the primary goal is realized [2]. Beam with 15mA peak current, 500μs pulse length and 50% beam-on duty factor has successfully transported through the MEBT into a temporary dump. In the 2nd run, the DTL tank1 has been commissioned with a temporary beam line. Due to the limited capacity of the temporary dump, the pulse length was shortened to 400μs (chopped) and the repetition rate was reduced to 5Hz. The other parameters like beam peak current and energy have reached the design values. A summary of baseline design parameters and beam commissioning results is shown in Table 1.

MEBT COMMISSIONING RESULTS

The MEBT is used for matching beam output from the RFQ into the following DTL transversely and longitudinally. It consists of 10 quadrupoles, 6 steering magnets and two 324MHz bunchers. The schematic layout of the MEBT is shown in Fig. 1. Besides optic elements, there is a suit of diagnostics to monitor beam.

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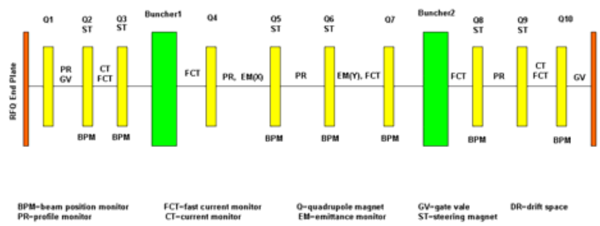

Figure 1: Layout of the CSNS MEBT.

Table 1: CSNS design vs. achieved beam parameters

	Baseline Design or Goal	Achieved
MEBT beam pulse length [μs]	420	500
MEBT pulse repetition rate [Hz]	25	25
Chopping rate [%]	50	50
LEBT peak current [mA]	20	31
MEBT peak current [mA]	15	18
DTL1 peak current [mA]	15	18
MEBT horiz emittance [π mm mrad (rms, norm)]	0.22	0.21
MEBT vertical emittance [π mm mrad (rms, norm)]	0.22	0.20
MEBT Beam Energy [MeV]	3.026	3.02±0.015
DTL1 output energy [MeV]	21.67	21.7±0.022

Transverse Twiss Parameters

For estimation of Twiss parameters at the beginning of the MEBT, beam profiles were measured with four wire scanners in the MEBT. If the wire scanner data is Gaussian and of high quality the easiest way to compute the beam sizes is fitting the profile with a Gaussian distribution. However, Guassian fit may not accurately represent the beam profile with halo. To calculate the RMS radius of this kind of profile, direct statistical calculation may be more suitable. Fig. 2 shows an example of the beam profile. The horizontal profile looks like Gaussian distribution while the vertical profile has significant halo "shoulders" [3].

After processing wire scanner data, estimation of the Twiss parameters was performed using beam sizes in conjunction with a beam propagation model. Table 2 lists the obtained Twiss parameters at the beginning of the MEBT.

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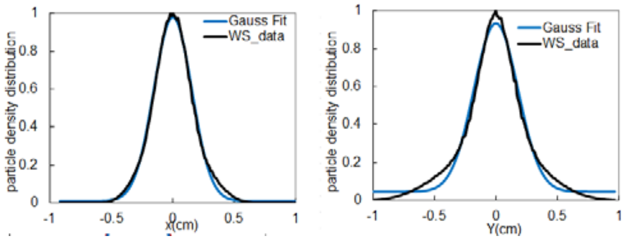


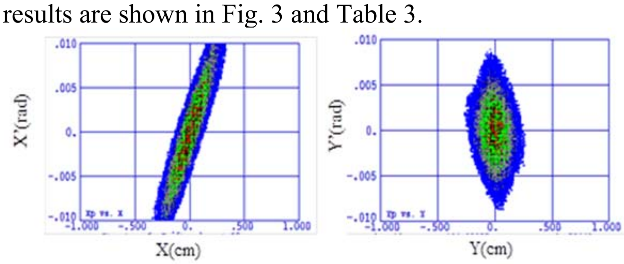
Figure 2: Beam profile measured with WS01 located after Q1.

Table 2: Twiss Parameters at the MEBT Entrance (I=15mA)

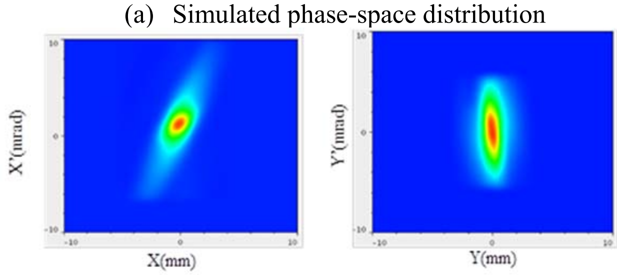
	α	β mm/mrad	Emittance rms, normalized mm mrad
Horizontal	-1.82	0.30	0.21
Vertical	1.32	0.10	0.20

A transverse emittance monitor is installed in the middle of the MEBT. It is double-slit type, and its first slit is located 1244mm downstream from the entrance of the MEBT.

We performed an experiment to test the accuracy of estimated Twiss parameters. First of all, we used the Twiss parameters in Table 2 as the initial beam parameters at the entrance of the MEBT. Secondly, we simulated the beam transporting through the MEBT with PARMILA [4]. Thirdly, at the location of the emittance monitor, we compared the simulated beam phase-space distributions with the measured ones from the emittance monitor. The results are shown in Fig. 3 and Table 3.



(a) Simulated phase-space distribution



(b) Measured phase-space distribution

Figure 3: Phase-space distribution at the emittance monitor.

Theoretically the two groups of parameters should be equal. However, due to measurement errors, errors in the beam size calculation, and errors in the model, the values have a little variation, which is considered acceptable.

Energy Measurement

Five FCTs are placed in the MEBT for energy measurement and RF tuning of buncher cavities. Fig. 4 shows the FCT layout. The drift length for the Time-of-Flight (TOF) measurement of the RFQ output energy is 2.29m (about 30βλ). The measured RFQ output energy is 3.02±0.015MeV, compared with 3.026MeV nominal design value.

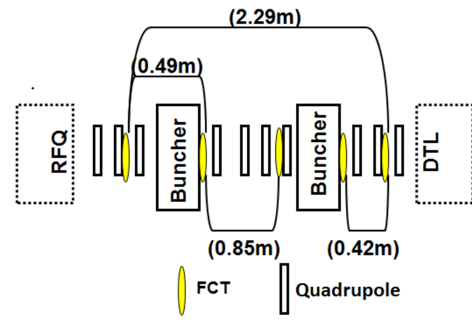


Figure 4: Schematic of FCT layout.

Table 3: Twiss Parameters at the Emittance Monitor (I=15mA)

	α	β mm/mrad	Emittance rms, normalized mm mrad
Horizontal			
Simulated	-2.46	0.69	0.21
Measured	-1.14	0.62	0.21
Vertical			
Simulated	0.16	0.30	0.20
Measured	0.02	0.37	0.18

RF Tuning of Buncher

At the beginning, the FCTs' electronic was unavailable, so we had to use BPMs downstream of bunchers to provide beam phase information. The basic procedure for determining the bunchering phase relies on the phase scan method. Fig. 5 shows an example of the buncher02, for which four phase scans at different amplitude were performed. The bunchering phase is located at the intersection of phase scan curves, which is -30degree.

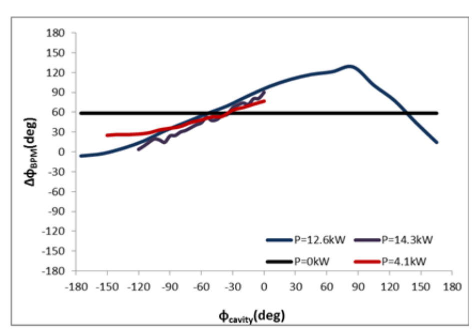


Figure 5: Measured phase differences (degrees) between two BPMs as functions of the buncher02 cavity phase.

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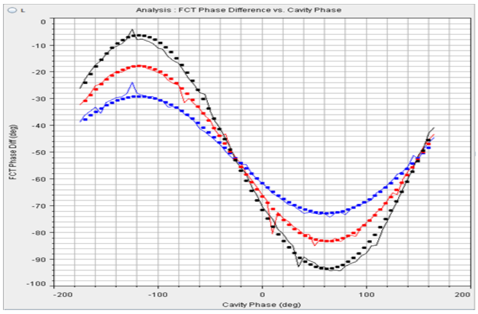

Figure 6: Measured phase differences (degrees) between two FCTs as functions of the buncher02 cavity phase. Plotted are experimental data (solid lines) and simulation results (solid circles) for three different RF amplitudes.

After the FCTs' electronic was available, a second technique was explored, which would also be used for tuning of the DTL tank 1. An application call PASTA was applied for phase scan and analysis [5]. It is based on the "phase-scan signature matching" approach [6]. In this method, the phase differences between two FCTs downstream of a cavity are measured as a function of the cavity phase. And then cavity amplitude, beam-cavity phase offset, input beam energy and FCTs' difference fudge of an online-model are varied to best fit those measured signatures.

As shown in Fig. 6, three sets of measured phase differences vs. cavity phase were recorded. The black curve was taken at nominal RF amplitude, the red one at 25% below nominal and the blue one at 50% below nominal. The bunchering phase of -27.9degree, measured in this way, agrees well with that measured by the first method. The bunchering phases of the buncher01 obtained by these two methods were -55degree and -60degree respectively. Besides, we found that the input energy, which is obtained along with the bunchering phase, is consistent with that measured by TOF in the MEBT. Table 4 summarizes these results.

Table 4: Measured RFQ Output Energy

	TOF	Buncer01 Scan	Buncher02 Scan	Design
W_{RFQ} (MeV)	3.02± 0.015	3.015	3.026	3.026

DTL COMISSIONING RESULTS

The drift tube linac consists of four accelerating tanks with final output energy of 80MeV. The transverse focusing is arranged in a FFDD lattice utilizing electric-magnet quadrupoles.

The first DTL tank has been commissioning with a temporary beam line. It contained a CT, a BPM, a wire scanner, an emittance monitor and two FCTs. The DTL1 commissioning results are summarized in Table 1. The design peak current of 15mA was readily achieved with 100% beam transmission. The goals of the DTL1 commissioning have been to demonstrate full system functionality, demonstrate beam acceleration with design beam parameters, test transverse focusing strategy, check the alignment accuracy and commission the diagnostic devices.

As mentioned before, the method of "phase scan signature matching" was applied for determining DTL tank RF setpoints too. A pair of FCTs in the temporary beam line was used to provide beam phase information. Fig. 7 shows the measured phase differences between two FCTs as functions of DTL1 RF phase. The blue curve was taken at nominal RF amplitude, the red one at 1% below nominal and the black one at 2% below nominal. It can be seen that the scan taken in the vicinity of the nominal amplitude fit better. The measured beam energy at the DTL1 exit is 21.722MeV, about 0.2% more than the design value of 21.677MeV.

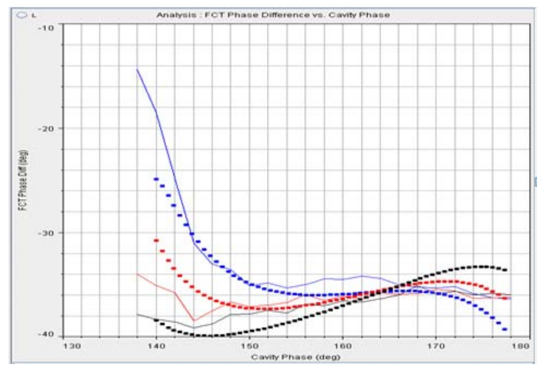

Figure 7: Plots of the DTL tank1 phase scan. Plotted are experimental data (solid lines) and simulation results (solid circles) for three different RF amplitudes.

CONCLUSION

The CSNS MEBT and DTL1 have been fully commissioned, the primary design goals of peak current, transverse emittance and beam energy have been achieved. The RFQ output energy, measured by phase scan method, agrees well with that measured by time-of-flight method. The remaining DTL tanks 2-4 have been installed in the tunnel. They will be commissioned in winter this year.

ACKNOWLEDGMENT

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