

BEAM PARAMETERS MEASUREMENT AND CORRECTION IN CSNS LINAC

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Abstract

All the beam parameters of China Spallation Neutron Source (CSNS) linac had achieved the acceptance goals in January 2018 after a 2-year commissioning. Parameters of the H- beam were carefully studied and corrected. Beam energy was measured and the energy dispersion are reduced. Transverse emittance are obtained by different tools and methods. Linear optics measurements and corrections were carried out under varied beam energies and peak intensities.

INTRODUCTION

The linear accelerator of CSNS [1] mainly consists of a 50KeV H- ion source, a four-vane radio frequency quadrupole accelerator(RFQ)and a four-tank drift tube linac(DTL) working at RF frequency of 324 MHz. The low energy beam transport line (LEBT) and medium energy beam transport line (MEBT) connect and match the above three accelerating sections. The linac to ring beam transport line (LRBT) which transports the beam from DTL to the Rapid-cycling Synchrotron (RCS) reserves the space for linac upgrading in the further. The total length of the straight section is 200m. The layout of the CSNS linac is shown in Fig. 1.

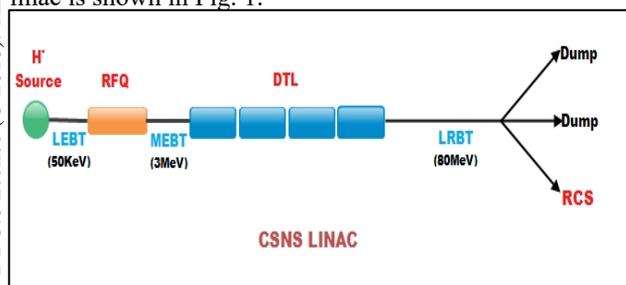


Figure 1: The CSNS Linac Layout.

The beam commissioning of linac started in April 2015 and was separated into 4 runs due to DTL tank installations and klystron failures. By January 2018, the beam peak current intensity reached 15mA and the beam energy achieved the design value of 80 MeV. The overall transport efficiency of DTL reached over 97%.

Beam parameters of CSNS linac were carefully measured and corrected during the commissioning. In this paper, the main beam parameters measurement and correction results will be displayed and discussed. The content includes: beam current intensity measurement and transport efficiency optimization, beam orbit correction, transverse emittance and twiss parameters measuring and matching, beam kinetic energy and momentum spread measurements .

BEAM PARAMETERS MEASUREMENT AND CORRECTION

Beam Current Intensity

The current beam power of CSNS linac is 1 KW with the peak current of 10 to 15 mA, the pulse width of 130 us, and the repetition rate of 25 Hz. Current transformers (CT) in linac beam line monitor the beam intensity and the transport efficiency. Figure 2 shows a set of CT signals along the linac.

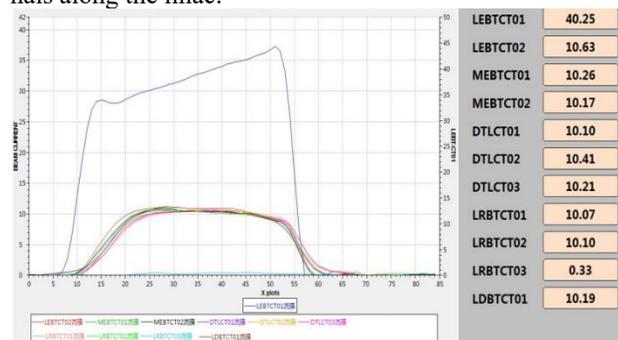


Figure 2: Current Transform Signals of CSNS Linac.

The transport efficiency is one of the most important parameters to be optimized in the linac beam commissioning. By beam orbit correction and operations of beam matching, transport efficiency is greatly improved thus the beam loss satisfies the design standard. The overall transport efficiency of DTL reached over 97%, there is still work to be done for further improvement.

Beam Orbit

Beam orbit is usually the first parameter to measure and correct in beam commissioning. The beam orbit distortion should be as small and as smooth as possible along the beam line, especially for CSNS linac with small aperture. Orbit correction application in XAL was adopted for the case of orbit manipulation in CSNS linac.



Figure 3: Beam Orbit of MEBT after Orbit Correction.

The Fig. 3 is the result of orbit correction for MEBT. The beam orbit of MEBT can be corrected from 1.5 mm

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to 0.5 mm. The beam orbit of LRBT can be corrected from 10mm to 2mm. After the corrections, the orbit deviations are suppressed and beam loss is also greatly reduced. However, the orbit correction for DTL is not carried out for no corrector and only one BPM inside.

Transverse Emittance

The transverse emittance of the beam is a key characteristic for high intensity particle accelerator. Measurement and study of emittance is very important for the prediction and control of the beam particle loss. A double scanning slit system and wire-scanners installed in linac are employed for the RMS emittance measurements. Different methods of measurement are introduced and the results are discussed[2].

Double scanning slit system is usually used in the low energy section of beam line. It is developed to get the emittance directly by measure the flux elements $f(x, x')$. Based on measured particle flux elements $f(x, x')$ passing through a relative position coordinate x with a relative velocity component x' , the RMS emittance can be calculated by statistical method. The particle distribution in phase space output by the JAVA code are showed in Figure 4.

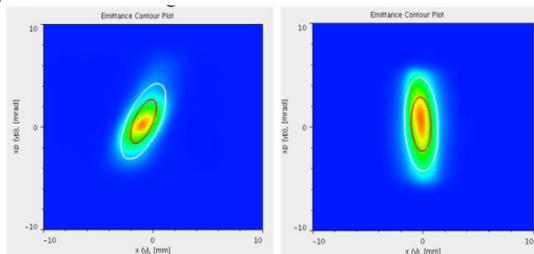


Figure 4: Particle Phase Ellipse by Double slit System: (Left- horizontal, Right-vertical).

Wire-scanner is the other kind of device used for transverse emittance measurement[2]. Two different methods for the wire-scanner measuring are employed. For the multi-changing focusing strength method, one wire-scanner and an upstream quadrupole with multi-changing focusing strength K are employed to perform the measurement. The other method is by scanning the beam parameters and usually 4 or more wire-scanners are needed. Beam transverse emittance measurement results obtained by different methods are presented as below, see Table 1.

Table 1: Emittance Measured by Different Methods

Emittance (MEBT)	Horizontal (mm.mrad)	Vertical (mm.mrad)
Double-Slit	2.28	2.24
Quads-Scanning	2.15	3.04
Multi-wire Scanner	2.02	3.55

Twiss Parameters

Matching of beam parameters is a very important step in the commissioning. The matching between the lattice and the beam parameters will make the beam envelope

evolve according to the design value, meet the requirements of DTL transmission and RCS injection, and thus reduce the beam loss.

To get the real transverse twiss parameters of beam, we also use the wire scanners installed on the MEBT and LRBT[3]. By minimizing the discrepancy between the measured values of wire scanners and the simulated values when different upstream twiss parameters initiates, we can get the real twiss parameters of beam.

Figure 5 shows the simulation and measurement results of beam phase ellipse at DTL exit. There is a clear difference between the real beam parameters and the simulation ones. This requires us to perform the corresponding matching adjustments for the actual beam parameters during the commissioning process. The process of beam commissioning shows that the twiss parameter measurement is accurate and effective, and the beam matching meets the design requirements.

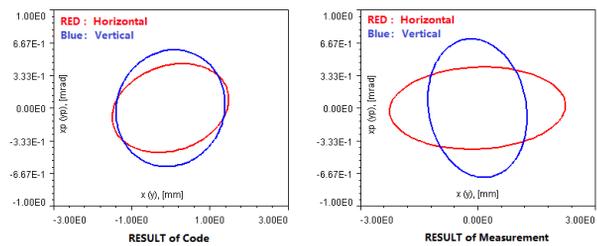


Figure 5: Transverse Phase Ellipse at DTL exit: (Left-simulations, Right-measurement).

Kinetic Energy and Momentum Spread

Beam energy is usually measured with various FCT pairs using the time of flight (TOF) method. The measurement can also be performed by phase scanning method. We scan the phase parameters of the RF cavity to obtain the relationship between the beam energy and the phase of RF cavities. Using the theoretical curves to fit the measured ones, the beam energy and some other parameters can be obtained.

The kinetic energy values of beam at each DTL tank's exit were measured by the two methods above. Deviation of measured beam energy from the design value is less than 1% [4]. The CSNS linac output energy is carefully measured and checked. The results show that the kinetic energy of linac is 80.36 MeV, while the design value is 80.01 MeV, which shows that the design energy of the linac was achieved.

The optimum momentum spread is about 0.1% at the inject point for inducing beam losses during the RCS injection. A debuncher cavity is installed in the LRBT to control the injection momentum spread.

After measuring and matching the beam parameters, we have obtained the actual emittance, alpha, beta, and dispersion functions of the beam. When the beam passes a dipole magnet, the momentum spread of the beam can be obtained by measuring the transverse distribution of the beam downstream the dipole. The momentum spread $\Delta P/P$ of beam at injection point of RCS is about 0.11% after the correction by debuncher.

CONCLUSION

We have presented part of the work in CSNS linac commissioning in this paper. The main parameters of beam in linac, which includes beam current intensity, beam orbit, transverse emittance, twiss parameters, kinetic energy and momentum spread were studied, measured and corrected.

So far, the beam energy, peak current, beam transmission efficiency of the CSNS linac have achieved the engineering acceptance parameters. Our further work is to optimize the parameters of machine and beam, to improve beam power and machine efficiency.

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