# BEAM COMMISSIONING OF TRANSPORT LINE LRBT OF CSNS *

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*Abstract*

The linac to ring beam transport line (LRBT) connects the 80 MeV linac and the 1.6 GeV rapid cycling synchrotron (RCS) of the China spallation neutron source (CSNS). The linac and LRBT commissioning have been in progress in the past months and the $H^-$ beam has been accelerated to the kinetic energy of 60MeV this April. The $H^-$ beam in LRBT which was measured and commissioned transported through the long beam line with low loss. The beam commissioning process and results of LRBT are presented and discussed.

## INTRODUCTION

China Spallation Neutron Source (CSNS) [1] is a high intensity accelerator based scientific research facility. The accelerator complex mainly consists of an $H^-$ ion linear accelerator of 80 MeV and a rapid cycling proton synchrotron (RCS) of 1.6 GeV as the extraction energy. The linac to Ring beam transport line (LRBT) connects the linear linac and the RCS while the ring to target beam transport line (RTBT) transports the extracted proton beam from RCS to the target.

The linear accelerator mainly consists of a 50KeV $H^-$ ion source, a 3.0MeV radio frequency quadrupole (RFQ) accelerator and a drift tube linear (DTL) accelerator. The low energy beam transport line (LEBT) and medium energy beam transport line (MEBT) connect the above three parts and give the beam matching transversally and longitudinally.

LRBT which transports $H^-$ beam from linac to the RCS injection point, was designed to optically match the linac and the RCS, decrease the energy spread and energy jitter, and reserve enough space for upgrading linac beam energy to 250MeV.

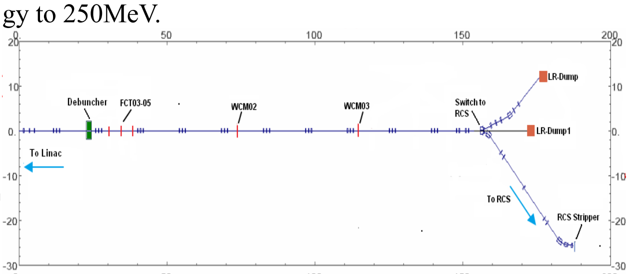


Figure 1: Layout of papers.

Figure 1 shows the layout of LRBT. LRBT is about 197 meter long and has 5 functional sections: 1) Matching section between the DTL FODO cells to LRBT Triplets. 2) Long straight section consists of 9 triplet cells, where 85 meter is reserved for the future upgrading. 3) Matching section between triplet cell and bending section. 4) 45 degree anti-symmetric achromatic section. 5) Transverse matching section for RCS injection. The main parameters are shown in table 1.

Table 1: Main Parameters of LRBT

| Parameters | Units | Values |
|---|---|---|
| Repetition Rate | Hz | 25 |
| Beam Power | KW | 5 |
| Kinetic Energy | MeV | 81 |
| Emittance (rms. un) | mm.mrad | 1.0 |
| Acceptance | mm.mrad | 25 |
| Momentum Spread | % | 0.1 |
| Peak Current | mA | 15 |
| Average Current | uA | 62.5 |

The installation and commissioning of the CSNS hardware systems have been accomplished. We have tested the stability of all the hardware devices, checked the magnet polarities. By now, the beam commissioning of the linear accelerator has been in progress for several months.

Due to the breakdown of one of the four DTL accelerator klystrons, we planned to decrease the kinetic energy of injecting beam for RCS from 80MeV to 60MeV before a new klystron is ready. This April, we have succeed to accelerate the $H^-$ beam with peak current density of 15mA to the kinetic energy of 60MeV. The Beam reached the LR-DUMP1 which is located at the end of the LRBT straight line with low beam losses.

In this paper, the major work we have fulfilled during the beam commissioning of LRBT will be introduced and discussed. The content includes: beam kinetic energy measurement, momentum spread correction, transverse emittance measurement, twiss parameters measurement and matching, beam orbit measurement and correction. The last part of the article is the conclusion and about the plan of next phase of the beam commissioning.

## BEAM ENERGY

The kinetic energy and momentum spread are very important parameters in the beam commissioning of LRBT. Acquired right value of beam energy, we can judge whether the DTL tanks is set to the right phase and field amplitude, and whether the right currents of the magnets are set. Beam energy was measured by using (TOF) method and the momentum spread can be corrected by debuncher cavity for specific requirements.

### Beam Energy Measurement

There are 5 FCT devices installed on LRBT for the beam measurements, see Figure 1. Beam energy can be measured with various FCT pairs using the time of flight (TOF) method.

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Measurements with the different FCT pairs should agree with each other within the expected accuracy. The measurement results show that the kinetic energy is 60.7 MeV to 61.2 MeV while the design value is 61.07MeV, which shows that we have reached the design energy of the linac.

### *Debuncher and Momentum Spread Correction*

The momentum spread of the core beam from the CSNS linac is about 0.1% while that of the longitudinal halo are much larger, and it continues increasing along the transmission in LRBT due to the space charge effects. The optimum momentum spread is about 0.1% at the inject point for inducing beam losses during the RCS injection. A debuncher cavity is utilized in the LRBT to minimize the injection momentum spread. The debuncher cavity is working at the RF phase of -90˚.

However, due to the breakdown of the klystron of the last DTL tank, the momentum spread of LRBT beam is much larger than the design value and the debuncher's location is not as suitable as design. Nonetheless, by carefully choosing the RF phase and RF voltage, the momentum jitter and spread can be corrected as well. Figure 2 gives the longitudinal particle distributions which show the debuncher's function of momentum.

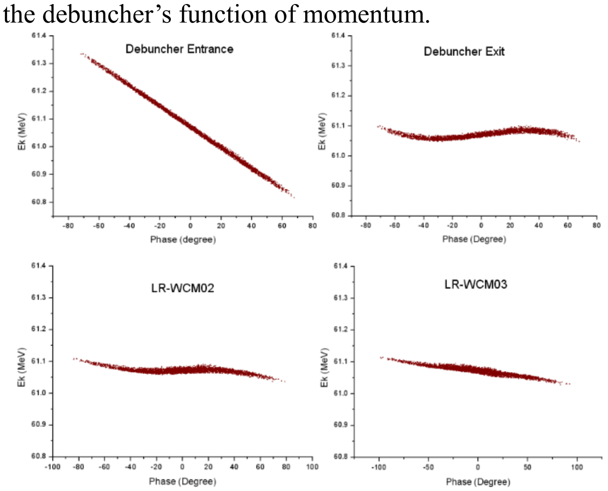


Figure 2: Longitudinal particle distributions at different locations of LRBT.

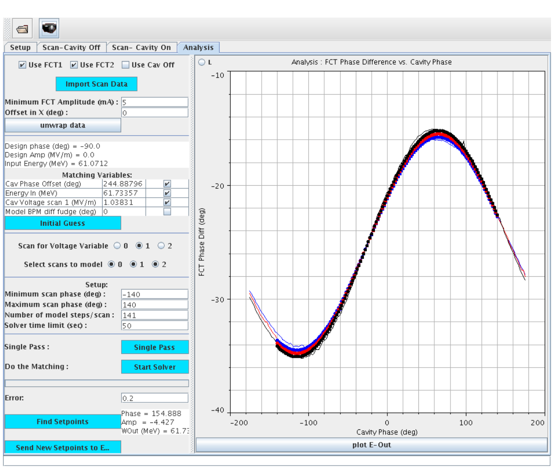


Figure 3: Phase scanning for LRBT debuncher cavity.

By scanning the RF phase of the debuncher cavity at different RF field amplitudes, we can get the right setting of the RF phase for the cavity. Figure 3 shows the application of phase scanning, the intersection of the lines represents the phase on which the particle is not accelerated and therefore is the right phase setting of the debuncher cavity. The momentum spread of the beam can be reduced to a certain value by setting an appropriate field amplitude to the cavity, so that the bunch length growth can be reduced. The wall current monitor WCM03 detected the micro beam pulse structure of 3 ns for the first time after the debuncher cavity began to work. Some of the BPMs downstream can work only when the debuncher is on due to the factor of beam bunch length.

## ORBIT CORRECTION

The orbit correction usually includes two parts: orbit distortion measurement and correction. The BPM sensor get the electrical signal when the beam transport through the monitor. By the electronic processing, the signals are converted into beam position information, which is the beam orbit. BPM is usually used to measure the orbit distortion, while the singular value decomposition (SVD) or least square algorithm is always adopted to correct the distortion [2]. By several times correction, the satisfying results of beam orbit can be obtained.

The orbit correction in transport line of CSNS is based on BPM-corrector response matrix (theoretical or measured). When an orbit correction is required, XAL orbit application will call the calculation module of solver to find the best beam orbit and the corresponding current values of correctors by multi-variable multi-target fitting and iterations. One of the principles of orbit correction is that, when orbit distortion is small, the number of correction magnets should as small as possible.

There are 14 BPMs and 13 correctors for orbit measurement and correction in the straight line of LRBT. We have confirmed the alignment offset of BPMs by the conventional beam based alignment (BBA) which is the examination by the responses to a change of strength of the quadrupole or the steering magnets [3].

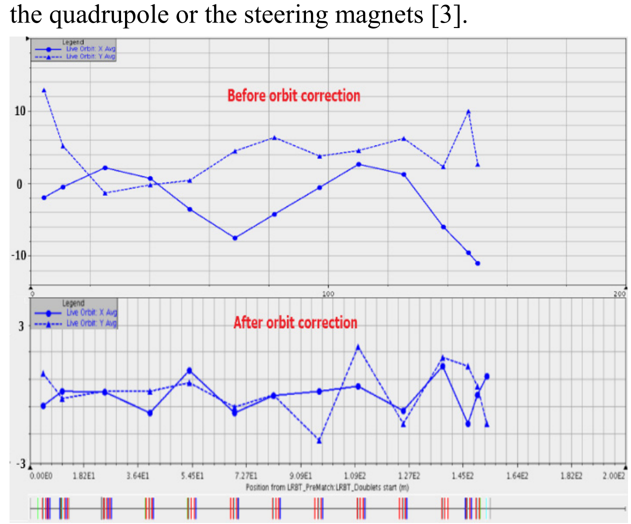


Figure 4: Orbit correction of LRBT.


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Due to the settlement and installation error, the four DTL tanks have a 0.03mrad deviation in vertical direction. And this error will lead to a 3mm orbit distortion at the DTL exit. Together with other errors, the vertical orbit distortion could be more than 10 mm in the front part of LRBT, see upper part of Figure 4. Since there is no corrector upstream the first BPM of LRBT, we can only calibrate the orbit at LRBPM01 to zero by tuning the correctors on MEBT.

CSNS orbit correction application based on XAL was employed for LRBT orbit correction. Using theoretical and measured BPM-corrector response matrix, the beam orbit distortions along LRBT are corrected, about 1mm in X direction and 2mm in Y direction while the aperture is 34mm, see Figure 4 lower part. We are now still working on reducing the orbit distortion further for a better result.

## TRANSVERSAL MATCHING

### *Emittance and Twiss Parameters Measurements*

To do the transverse matching, first is to determine the real transversal twiss parameters $\alpha, \beta$ and emittance $\varepsilon$. By measuring the wire scanners installed on the first part of LRBT, we can get both the transversal emittance and twiss parameters of the beam from linac.

An XAL application wire analysis is employed to do the emittance $\varepsilon$ and twiss $\alpha, \beta$ parameters calculation. The algorithm based on wire scanner profile measurement at three or more locations along the beam line is adopted from LANL [4]. First, we set the initial RMS emittance $\varepsilon$, twiss parameters $\alpha, \beta$ and the searching step and scale. Then call the XAL online model or PARMILA code which including space charge effect to do the beam transport calculation [5]. By iteration and searching, we can minimize the discrepancy between the wire scanners' experimental data and the results given by the codes. When the discrepancy reach the satisfaction standard we set, iteration and searching stop and the final twiss parameters and emittance of beam at the LRBT entrance are obtained.

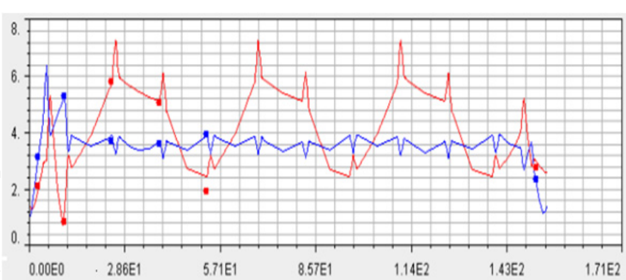


Figure 5: Transversal parameters calculation of LRBT.

The calculation of transversal twiss parameters at the entrance of LRBT by the wire analysis application is shown in Figure 5. The red and blue lines represent the beta functions in X and Y plane respectively. The red and blue dots represent the RMS radius of beam profile in X and Y planes at each wire scanner's location. It shows that the mismatch in the X direction is very serious if the lattice is set up based on code simulations. From the result, we can get the transversal twiss parameters and emittance of real beam and do the matching again.

### *Beam Matching*

There are 6 independent quadrupoles in the front of the LRBT, which are used to match the beam from the DTL. Once a set of twiss parameters at a given upstream location is obtained from the previous step, we can rematch the beam and make a new lattice.

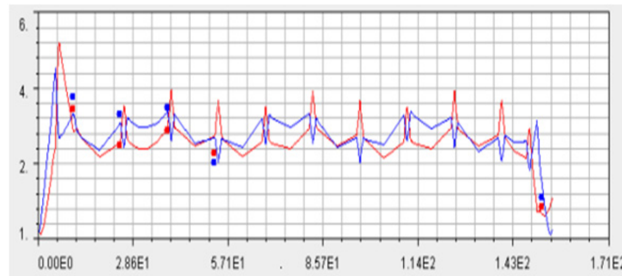


Figure 6: Wire scanner results after matching.

Figure 6 shows another set of wire scanner results of which the measurements took place a few day later than the previous one. Though the beam parameters at the entrance of LRBT changed, we still can see from Figure 6 that the matching was much better, and the beam losses were greatly reduced.

## CONCLUSION

In this paper we present the commissioning work of the LRBT straight line in CSNS. The parameters of the beam in LRBT were measured and tuned. The $H^-$ particles transported through the long beam line with low loss. The energy was measured and the momentum spread was corrected. The beam orbit distortion was measured and minimized. Transversal parameters were obtained and the beam was optically matched.

Now, we're at the end of beam commissioning for the CSNS linac. The major work of the next phase is the commissioning of RCS accelerator and we are going to work on the injection of RCS soon.

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