SPACE CHARGE EFFECTS STUDY AND OPTIMIZATION IN CSNS/LRBT*

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Abstract

The linac to ring beam transport line (LRBT) of China Spallation Neutron Source (CSNS) connecting the linac and the rapid cycling synchrotron (RCS) transports 80 MeV negative hydrogen ions (H-) beams for RCS injection. Space charge effect in LRBT is significant due to small emittance and high current density of the beam, which is a major cause of emittance growth and beam loss. An achromatic transverse optical matching was performed by TRACE 3D code. Emittance growths of beams with different initial distributions in different LRBT lattices were studied separately. Simulation results show that the LRBT design with triplet can mitigate the emittance growth by lattice optimization of the front matching section and no beam loss occurs at 15mA. The location and parameters of the debuncher in LRBT were also optimized to reduce the momentum spread and energy jitter.

INTRODUCTION

China Spallation Neutron Source (CSNS) is a high performance pulsed neutron source[1]. The accelerator system consists of a negative hydrogen ions (H-) linac and a 1.6GeV proton rapid cycling synchrotron (RCS).

The linac to ring beam transport line (LRBT) transports 81 MeV H- beams at 25 Hz repetition rate for RCS injection. The peak current density of the LRBT beam is 15mA and it is highly bunched due to the FODO structure of DTL. Therefore, the low energy, high current density and small emittance of beam make the space charge effect in LRBT significant.

Space charge of transverse can make rapid growth of emittance while the longitudinal can cause momentum spread and energy jitter. They will both introduce more beam losses in the processes of transporting or injecting.

By optimizing the lattice, transverse space charge effect in LRBT could be suppressed. And debuncher with proper parameters could greatly reduce the effects caused by longitudinal space charge.

TRANSVERSE SPACE CHARGE EFFECT

The 197.5m long LRBT main line has 5 functional sections: 1) front matching section to match DTL FODO to LRBT triplet. 2) Long straight section with periodic lattice structure, where a debuncher and transverse collimators located. 3) Matching section between triplet cells and bending section which consists of two doublets. 4) 45° anti-symmetric achromatic section. 5) Matching section for injection into ring.

By optimizing the lattice parameters, we can reduce the emittance growth caused by space charge effect. The major work we have accomplished are as follow: 1) re-match of the linear optics with space charge effects; 2)

choose proper periodic focusing cells which have comparatively large Beta function; 3) modify the match section in the front according to the initial beam parameter.

Re-matching of linear optics with space charge

The linear optics of LRBT was initially designed and matched by MAD code where the space charge is not considered. However, the space charge force of real beams with different current density or distribution will cause different mismatches to the designed optics. Theory shows that increasing quadrupole strengths in a proper way would compensate for the linear part of the space charge. And Trace 3D code could undertake the work of lattice calculation and matching when linear part of space charge force is take in account [2].
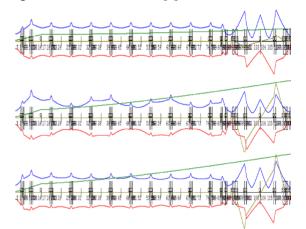

Figure 1: Comparison of LRBT beam envelops and dispersion functions by TRACE 3D: without space charge (upper), mismatching (middle), re-match (lower).

Fig.1 upper shows the Trace 3D plots of LRBT beam transverse envelops and dispersion when there is no space charge considered. Fig.1 middle shows the mismatch situation when space charge is include in calculation. The RMS envelops present non-periodic oscillations in the periodic lattice section and the values at the waist increase. This could bring the growth of emittance as well as more beam losses. Meanwhile, the matched conditions in the injecting point of RCS no longer satisfied. Fig.1 below shows the result after matching by Trace 3D from which we can see that space charge effect has been compensated.

Comparison of different periodic lattice cells

Long straight section is the longest part of LRBT which consists of numbers of periodic cells. A debuncher and transverse collimators are located here. Emittance growth issue caused by space charge effect is also the prior consideration in the long straight section design.

05 Beam Dynamics and Electromagnetic Fields

D01 Beam Optics - Lattices, Correction Schemes, Transport

The tradition choices of transport line lattice are FODO, doublet and triplet. E.g. FODO structures are most used in SNS and J-PARC transport lines. PARMILA[3] code was employed to calculate the emittance growths in different LRBT lattices which consist of FODOs, doublets, triplets respectively. Fig.2 shows the results, which indicate that the emittance growth rates in these structure are close.

Three stripping foils are designed in the straight section, once the halo particles hit on foils, they will be converted into protons.The tripped protons will be transported along with the H⁻ beam until the switch dipole. Triplet has the specific property of matching both the H⁻ minus and the proton beams, ensures low beam losses in the straight section. So triplet was finally adopted in the long straight section lattice design. The horizontal phase advance of the triplet is 60˚, which is the optimal value for transverse collimation [4].
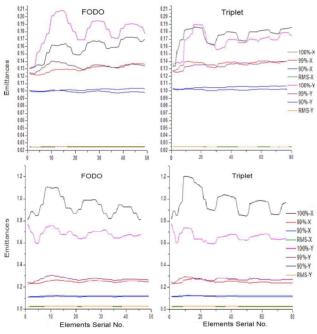

Figure 2: Beam emittance (cm·mrad) evolutions in FODO and triplet cells with different initial distribution uniform (upper), real (lower).

Front matching section optimization

The large bunch population and small beam sizes of CSNS linac output beam result in significant space charge effect. Simulation results show that most of the emittance growth generates in the front matching section.

As the small bunch size at the LRBT entrance, thus the strong space charge force should be weakened before entering the first quadrupole. The distance between the last quadrupole in DTL and the first quadrupole in LRBT can't be too short to de-bunch. The first three quadrupoles was designed to be a triplet and with the next three quads can perform the matching to the long straight section.

The lengths of the first four drifts are optimized to be 4.2m, 0.8m, 0.8m, and 4.2m respectively. PARMILA

results after changing this section are illustrated in Fig.3. Compared with the results showed in Fig.2, Fig.3 shows that the emittance growths in the section are reduced through lattice optimization.
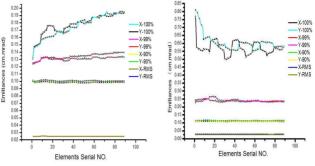

Figure 3: Beam emittance evolutions in LRBT after lattice optimization with different initial distributions: Uniform (left), real (right).

LONGITUDINAL SPACE CHARGE EFFECT

Debuncher

Momentum spread of the core beam from the linac is about 0.1%, while it is much larger for the longitudinal beam halo. Also, the momentum spread will continuously increase as well during the transmission in LRBT due to the longitudinal space charge force.

The momentum spread is the prime issue to induce beam losses in the RCS. In the long straight section there is a debuncher designed to control it. The debuncher can also correct the momentum jitter of the linac beam when it is less than $\pm 0.2\%$. By optimizing the drift distance, cavity voltage and RF phase, the momentum jitter and spread can be well corrected.

The drift distance is related to the debuncher's location. Longitudinal bunch length at the debuncher's location has to be in the linear part of the cosine electric field. The cavity voltage of debuncher depends on the power of RF source. Table 1 gives the basic parameters of the LRBT debuncher.

Table 1: Basic Parameters of LRBT Debuncher

Parameters	Value
Beam energy (MeV)	80.1
Peak current density (mA)	15
RF frequency (MHz)	324
E_0TL (KV)	360
Aperture ϕ (mm)	40
Dist. to linac exit (m)	23.8
Momentum spread at injection point	0.1%

The debuncher cavity voltage is set to be 360KV and located 23.8m from the LRBT start point. PARMILA simulation results in fig.4 show that, the energy spread of the 80MeV H⁻ beam through this debuncher is about 0.2% at the RCS injection point. Under this condition, the

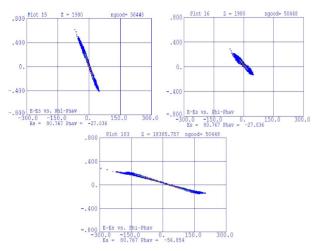coupling of transverse emittances reaches the minimum [5] and less beam losses occur in the RCS injection.

Figure 4: Longitudinal phase plots at debuncher entrance (upper L), debuncher exit (upper R) and RCS injection point (lower).

Momentum collimator

The linac output beam may have a long tail consists of lower energy particles. These particles could be pushed out of the phase range that the debuncher can correct by the longitudinal space charge force.

Momentum collimator of LRBT is installed in the front part of 45˚ bending section where the dispersion function value is large. The particles with momentum deviation over 0.5% will be stopped inside the collimator, instead of anywhere else in LRBT.

CONCLUSION

In this paper we have studied the space charge effects in CSNS/LRBT which is significant due to the low energy, high current density and small emittance of the beam.

For the space charge effect in transverse, we have re-matched the linear optics, compared different lattice structures of the long straight section and the triplet was adopted. The lattice of front match section where the emittance grows the fastest was optimized.

For the longitudinal space charge, a debuncher was designed to reduce the momentum spread to an optimal value. Meanwhile, momentum collimator was installed in the 45˚ bending section to cut off the beam tail.

By these work above, the space charge effect issues in LRBT could be controlled and partially compensated.

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