BEAM TRANSPORT LINES FOR THE CSNS*

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Abstract

This paper presents the design of two beam transport lines at the CSNS: one is the injection line from the linac to the RCS and the other is the target line from the RCS to the target station. In the injection beam line, space charge effects, transverse halo collimation, momentum tail collimation and debunching are the main concerned topics. A new method of using triplet cells and stripping foils is used to collimate transverse halo. A long straight section is reserved for the future upgrading linac and debuncher. In the target beam line, large halo emittance, beam stability at the target due to kicker failures and beam jitters, shielding of back-scattering neutrons from the target are main concerned topics. Special bi-gap magnets will be used to reduce beam losses in the collimators in front of the target.

INTRODUCTION

The CSNS (China Spallation Neutron Source) accelerators are to deliver proton beam power of 120 kW at phase I and 240 kW at phase II [1-3]. There are two beam transport lines at the CSNS: the LRBT transfers the H-minus beam from the linac injector to the RCS ring; the RTBT transfers the high power proton beam from the RCS to the target. There are also auxiliary branch lines (LDBT, RDBT, REBT) attached to the two trunk lines, and transfer beams to the beam dumps and experimental area. As the project will be constructed in phases, the beam transport lines should be designed to facilitate the upgrading with minimum cost. The beam lines have been designed to have an upgrading potential to 500 kW by extending the linac energy to 230 MeV.

Table 1: Beam Powers in the CSNS Transport Lines

	CSNS-I	CSNS-II	CSNS-II’
LRBT (kW)	6.6	20.9	77.0
LDBT (kW)	6.6	7.5	7.5
RTBT (kW)	120	240	500
RDBT (kW	7.5	7.5	7.5
REBT (kW)	<2	<2	-

With the high beam power, beam losses along the whole accelerators should be very carefully dealt in order to control the radiation level and maintain the hands-on maintenance as it is possible. This is one of the main concerns in designing the two beam transport lines. The concerning beam powers in the beam lines are shown in Table 1.

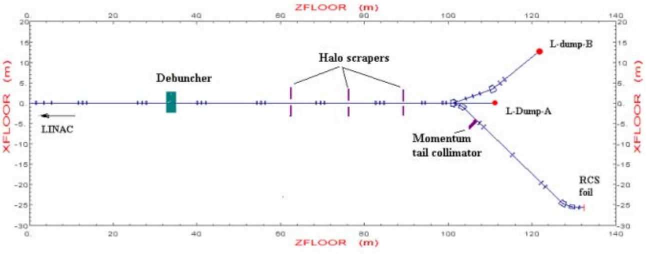

Figure 1: LRBT layout.

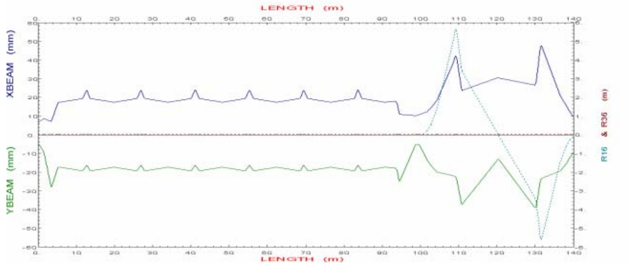

Figure 2: Beam envelopes and dispersions in LRBT.

BEAM TRANSPORT FROM LINAC TO RCS AND DUMPS

The layout of the LRBT including the adjoint beam lines is shown in Figure 1. The main functions of the LRBT are: transferring H-minus beam from the injector linac to the RCS, matching the beam onto the stripping foil in the RCS, momentum correction by using a debuncher, transferring H-minus beam to the two linac development dumps, transverse beam halo collimation by using foil scrapers, momentum tail collimation by using a collimator at the bending section with high dispersion, dumping the scraped particles to the linac dumps. In an alternate design for the RCS injection system [4], the vertical painting bump magnets are also in the LRBT. Figure 2 shows the beam envelopes and dispersion in the LRBT trunk line.

Space Charge Effects

In the LRBT, given the beam energy of 80/130 MeV, peak current of 20/35 mA and small bunch length just after the linac, the space charge effects play important role. On the one hand, it will increase the momentum

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spread; on the other hand, it will alter the normal periodic focusing structure in the straight section and the achromatism in the bending section.

Preliminary studies show that the effects are only of importance in the first section of the beam line where the beam is very bunched. One needs to compensate the defocusing effect and choose appropriate debunching distance for the debuncher. Afterwards, the effect becomes much weaker, only minor adjustment is needed.

Transverse Beam Halo Collimation

The beam pre-accelerated in the linac is expected to have a beam core of small emittance and a sparse halo of large emittance. In order to avoid beam losses in the RCS, the beam will be cleaned up by scrapping the most halo particles before injecting into the ring.

A group of stripping foils will be installed in the straight section of the beam line to convert the halo particles hit on them into protons. With the special designed triplet cells of 60° in phase advance, the protons will be transported along the main H-minus beam until the switch bending magnet. From there, the proton beam will be separated from the H-minus beam and transported to the beam dump (dump-B) due to their different charge. The triplet cells structure, which has the property of being matched with both H-minus and proton beams simultaneously, ensures almost no beam losses in the straight section, see Figure 3.

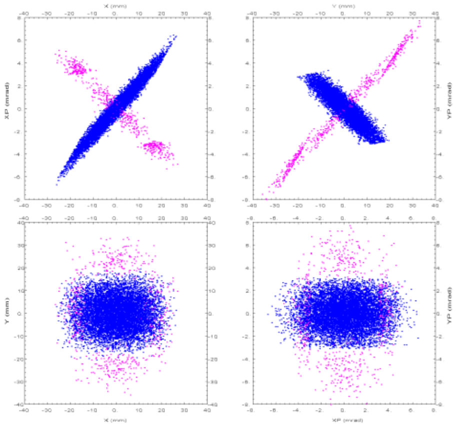

Figure 3: Beam distribution in phase spaces at a quad entrance after first stage scraping (blue for H-, red for H+).

The proton beam can be used for other kinds of applications without affecting the normal CSNS operation.

Momentum Correction

Similar to the transverse plane, the momentum spread of the core beam from the linac is relatively small of about 0.1% but the beam halo in the longitudinal plane has larger momentum spread. Even more, the space charge effects will increase the momentum spread significantly. As the momentum spread is a key issue to control the beam losses during the RF capture process in the RCS, a debuncher is planned in the LRBT to decrease the momentum spread within ±0.1%. The momentum jitter of the linac beam is also corrected by the same debuncher if it is smaller than ±0.2%. The drift distance and the required RF cavity voltage are optimised for both the final momentum spread and the momentum acceptance and for the different CSNS phases.

Long momentum tail has been observed in many linac accelerators. As the momentum deviation of the particles in the tail is too large to be corrected by the debuncher and even enhanced by it, a momentum collimator at the highly dispersive location in the bending section is considered to remove the particles. The impact to the collimator is large, thus the direct absorbing method will be used.

Transport to Linac Beam Dumps

The two beam dumps are designed for the commissioning and set-up of the linac as well as for dumping the scraped halo particles. The beam dump (dump-A) located straightly behind the switch magnet is of small beam power and used for early stage development of the linac. It will act as an emergence dump and absorb the partially stripped H0 particles at the halo scrapers. No additional quadrupoles except those before the switch magnet can be optimized to produce better beam spot.

However, the beam dump (dump-B) of higher power is designed to have large beam spot to facilitate the heat mitigation. During normal operation, most halo particles stripped at the scrapers are either stopped here or used for other applications. The branch beam line also called LDBT, has a symmetric bending structure, and can be tuned to be either achromatic in normal operation or with large dispersion when carrying out the momentum measurement.

Matching into the RCS

The injection stripping foil is located at the middle point of one of the dispersion-free long straights where it has the property of double-waist. To reduce the halo production during the phase space painting, the last part of the LRBT is designed to have a mismatching or special matching to the RCS lattice. The achromatism is required even in the presence of the space charge effect, thus the last four quadrupoles in the straight section and the five in the bending section are all together for the betatron and dispersion matching.

BEAM TRANSPORT FROM RCS TO TARGET AND RING DUMP

The layout of the RTBT including the adjoint beam lines is shown in Figure 4. The main functions of the RTBT are: transferring the proton extracted from the RCS to the target, matching the beam profile requirement at the target, transferring beam to the ring development dump or to an experiment station. As the total beam power is in hundreds of kW, it is very important to have a very low beam loss rate to allow hands-on maintenance. The failure and jitter from the extraction kickers are considered the main causes to the beam losses.

The backscattering neutrons from the target are harmful to the magnets and the other devices in the last part of the RTBT, therefore, both collimators and radiation-resistant magnets are of provision.

The FODO based focusing structure is adopted in the RTBT (Figure 5). Although the emittance of beam core is shrunk to less 80 πmm.mrad during the acceleration, it is uncertain how the halo portion is. Therefore, the acceptance of the RTBT is defined to be 350 πmm.mrad same as the RCS collimation acceptance. In addition, the beam jitter due to the kickers' strength variation of 3% is tolerated.

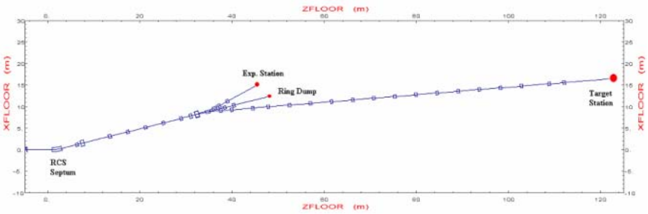

Figure 4: Layout of RTBT.

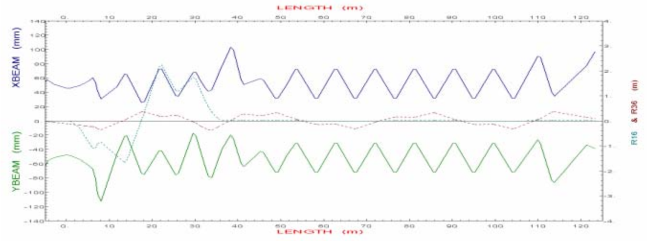

Figure 5: Beam envelopes and dispersions in RTBT.

Matching to the Requirement of the Beam Profile at the Target

The beam profile (footprint) at the target is defined to be 80 mm (h) * 32 mm (v) by the target design, and this corresponds to the core beam. As mentioned earlier, the halo emittance can be as large as 350 πmm.mrad. In order to avoid or reduce the direct loss of the halo particles in the collimators and the target area outside the footprint, non-linear magnets or special bi-gap dipoles [5] are considered to fold the halo particles into the footprint at the target. These magnets are also helpful to centre the beam onto the target in the case of kicker failures or large beam jitter.

Following the similar design in the ESS [6], the last four quadrupoles can produce two waists for the two collimators in both horizontal and vertical planes. For the non-linear magnets to be effective appropriate phase advances between the non-linear magnets and the target and large aspect ratio are also needed.

Beam Transport to the Ring Dump and the Experimental Station

The switchyard is designed to deliver the beam to three different directions: in normal case, the beam is directed to the target, and from the extraction septum to the switch magnet it composes an achromatic bending section; in the case of beam commissioning or set-up, the beam goes straightly onto the ring dump; during normal operation, the beam pulses can be partially sent to the experimental station with a fast switch magnet of low repetition rate. The way out to the experimental station can also be considered to transport the beam to the second target station in the future's upgrading. Two pairs of doublet quadrupoles are employed to produce the required beam profiles at both the beam dump and the experimental station each.

CONCLUSIONS

The beam transport lines from the linac to the RCS and from the RCS to target have been designed. Special attentions have been paid to the momentum correction, transverse halo collimation, different usage of the beam dumps in the LRBT, and beam profile matching to target and beam loss control in the RTBT. Both beam lines are designed to facilitate the future upgrading.

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