COMMISSIONING AND OPERATION OF THE COLLIMATION SYSTEM AT THE RCS OF CSNS

Shouyan Xu[1, 2, †], Kai Zhou[1, 2], Jianliang Chen[1, 2], Mingyang Huang[1, 2], Sheng Wang[1, 2]
[1]Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing, China
[2]Spallation Neutron Source Science Centre, Dongguan, China

Abstract

In high-intensity proton synchrotrons, minimizing particle losses during machine operation is crucial to prevent radiation damage. Uncontrolled beam loss is a major obstacle to achieve higher beam intensity and power in these synchrotrons. The beam collimation system plays a vital role in removing halo particles and localizing beam loss. It serves as a critical tool for controlling uncontrolled beam loss in high-power proton accelerators. To address the issue of uncontrolled beam loss, a transverse collimation system was designed for the RCS of CSNS. Initially, the design included a two-stage collimator. However, during the beam commissioning of CSNS, it was found that the collimation efficiency was compromised due to insufficient phase advance between the primary and secondary collimators. As a result, the designed two-stage collimator was modified to a one-stage collimator. Through optimization of the collimation system, the beam loss was effectively localized within the collimator area, resulting in a significant reduction in uncontrolled beam loss. As a result, CSNS achieved the design power of 100 kW with minimal uncontrolled beam loss.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy, striking a solid metal target to produce spallation neutrons. CSNS has two major accelerator systems, a linear accelerator (80 MeV Linac) and a 1.6 GeV rapid cycling synchrotron (RCS). The DTL raises the H^- beam energy to 80 MeV, and after the H^- beam is converted to a proton beam via a stripping foil, the RCS accumulates and accelerates the proton beam to 1.6 GeV. The 1.6 GeV proton beam is extracted to the target at a repetition rate of 25 Hz. The RCS is designed to extract a beam power of 100 kW, corresponding to 1.56×10^{13} protons per pulse in two bunches. The lattice of the RCS is a four-fold structure based on triplet cells. The entire ring comprises 16 triplet cells, with a circumference of 227.92 m. In each super-period, an 11 m long drift space is available between two triplet cells, providing uninterrupted space for accommodating the injection, extraction, acceleration, and transverse collimation system, as shown in Fig. 1. Table 1 provides the primary parameters of the RCS [1, 2].

For high-intensity proton synchrotrons, minimizing particle losses during machine operation is essential to avoid radiation damage. The use of collimation system is an important means of controlling uncontrolled beam loss in high-power proton accelerators. The beam collimation system can remove halo particles and to localize the beam loss. The design transverse collimator is a two-stage collimator. During the beam commissioning of CSNS, the designed two-stage collimator has been changed to one-stage collimator to overcome the problem of low collimation efficiency caused by insufficient phase shift between the primary and secondary collimators. By optimizing the collimation system, the beam loss is well localized in the collimator area, effectively reducing uncontrolled beam loss. This paper introduces the process of collimation system optimization at the RCS of CSNS.

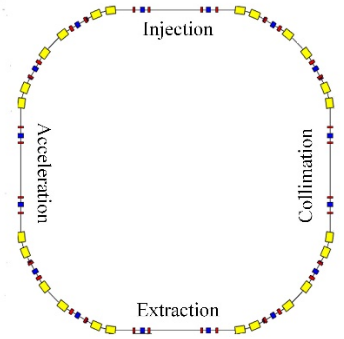

Figure 1: The schematic layout of the RCS of CSNS.

Table 1: The Primary Parameters of the RCS of CSNS

Parameters	Value
Output Beam Power (kW)	100
Injection Energy (MeV)	80
Extraction Energy (GeV)	1.6
Pulse repetition rate (Hz)	25
Ramping Pattern	Sinusoidal
Acceleration Time (ms)	20
Circumference (m)	227.92
Number of Dipoles	24
Number of Quadrupoles	48
Lattice Structure	Triplet
Nominal Betatron Tunes (H/V)	4.86/4.80
Natural Chromaticity (H/V)	-4.0/-8.2
Ring Acceptance (π·mm·mrad)	540
Number of Bunches	2

---

† email address: xusy@ihep.ac.cn

DESIGN OF THE TRANSVERSE COLLIMATION SYSTEM

The transverse collimation system of at the RCS of CSNS is designed to be a two-stage collimation system, consisting of a primary collimator and four secondary collimators (Fig. 2) [3]. The primary collimator is responsible for removing the beam halo, while the secondary collimators absorb the evolving primary halo based on the phase advance. The phase advances between the primary collimator and the secondary collimators are as follows: (9°, 9°), (21°, 22°), (38°, 41°), and (62°, 67°) respectively. The emittance of the beam core is 300 π·mm·mrad, and the vacuum pipe has an acceptance of 540 π·mm·mrad. The primary collimator has an acceptance set at 350 π·mm·mrad, while the secondary collimator has an acceptance set at 420 π·mm·mrad. The collimation efficiency is expected to exceed 95%.

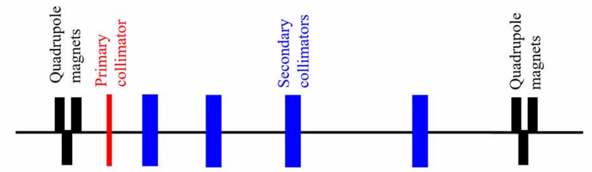

Figure 2: The schematic layout of the acceleration system.

BEAM COMMISSIONING RESULTS OF THE COLLIMATION SYSTEM

During the beam commissioning of CSNS, it was observed that the collimation efficiency of the transverse collimation system is lower than 90%. There are several crucial beam loss points in addition to the collimation area, as depicted in Fig. 3.

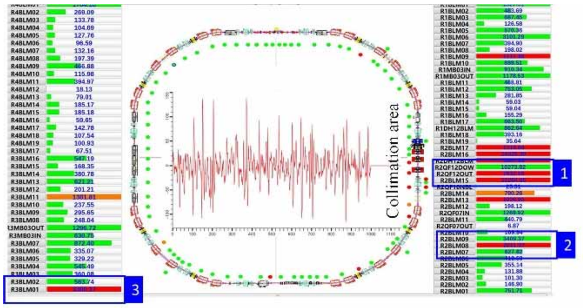

Figure 3: The beam loss distribution (BLM signals) along the RCS with the transverse collimator.

In a two-stage collimation system, collimation efficiency is influenced by two crucial factors: the phase advance between the primary collimator and the secondary collimators, and the ratio of the physical aperture to the aperture of the primary collimator. The phase advance between the primary collimator and the secondary collimator, which is less than 90°, plays a crucial limitation in enhancing collimation efficiency. In order to analyse the reasons for the low collimation efficiency, we use the PyORBIT [5] code to simulate the collimation efficiency at different ratios of the ring acceptance to the beam emittance. Once a machine is built, its physical aperture cannot be changed. We change the value of the beam emittance by changing the number of particles stored in the RCS and the space charge effects. The simulated emittances for various stored particle numbers (i.e., different equivalent beam powers) are illustrated in Fig. 4. The ratio of the ring acceptance to the beam emittance and collimation efficiency for different beam powers are compared in Fig. 5. Due to various dynamic errors and the limited painting area, the beam emittance exceeds the design value, while the ring acceptance falls short of the intended value. The ratio of the ring acceptance to the beam emittance, which is about 1.2, is significantly lower than the intended design value of 1.8. Due to the small phase advance between the primary collimator and the secondary collimator and the ratio of the ring acceptance to the beam emittance, the collimation efficiency was greatly compromised.

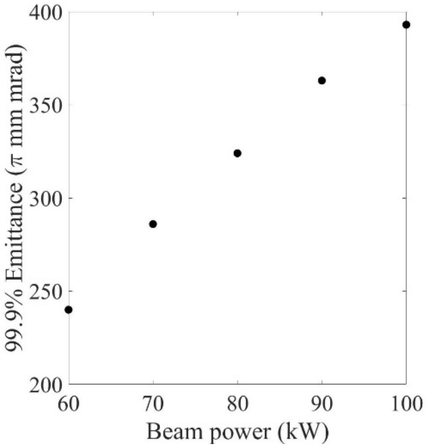

Figure 4: The simulated emittances for different beam powers.

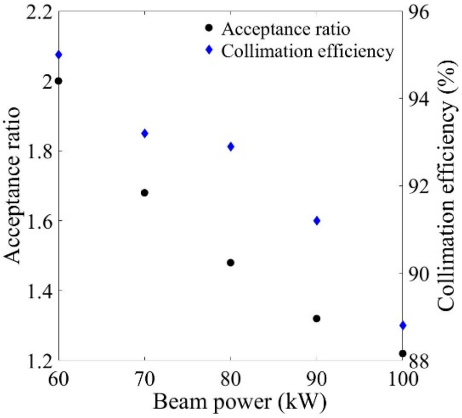

Figure 5: The ratios of the ring acceptance to the beam emittance and collimation efficiency for different beam powers.

TRANSEVERSE COLLIMATION SYSTEM OPTIMIZATION

Once the machine is constructed, the physical aperture remains fixed. The phase advance can only be adjusted within a limited range. The beam emittance cannot be optimized below the design value when operating at the intended beam power of 100 kW at the RCS of CSNS.

To address the low efficiency of the transverse collimation system, the originally designed two-stage collimator has been modified to a one-stage collimator. The beam halo now passes through the main collimator without scattering and is directly absorbed by the first secondary collimator.

The majority of additional instances that scatter is effectively absorbed by subsequent downstream secondary collimators. By optimizing the collimation system, the beam loss was successfully confined within the designated collimator area, leading to a substantial decrease in uncontrolled beam loss. Consequently, the three critical beam loss points, in addition to the collimation area, were noticeably reduced, as depicted in Fig. 6. CSNS accomplished its design power of 100 kW with minimal uncontrolled beam loss [6].

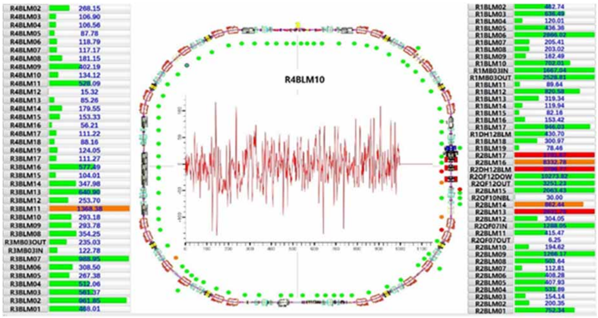

Figure 6: The beam loss distribution along the RCS with the transverse collimator after the collimation is optimized.

CONCLUSION

A two-stage transverse collimation system is designed to address the issue of uncontrolled beam loss at the RCS of CSNS. Due to the small phase advance between the primary collimator and the secondary collimators and the ratio of the ring acceptance to the beam emittance, the collimation efficiency was greatly compromised. To address the low efficiency of the transverse collimation system, the originally designed two-stage collimator has been modified to a one-stage collimator. The beam halo passes through the main collimator without scattering and is directly absorbed by the secondary collimators. Due to the relatively moderate energy of lost particles in the RCS, the secondary collimator has effectively showcased an impressive absorption effect on beam halo particles. By optimizing the collimation system, the beam loss was successfully confined within the designated collimator area. CSNS accomplished its design power of 100 kW with minimal uncontrolled beam loss.

REFERENCES

[1] S. N. Fu, H. S. Chen, *et al.*, "Status of CSNS project", in *Proc. IPAC'13*, Shanghai, China, May 2013, pp. 3995-3999.

[2] S. Wang, Y. An, *et al.*, "An overview of design for CSNS/RCS and beam transport", *Sci. China Phys. Mech. Astron*, vol. 54, no. 2, pp. s239-s244, 2011. `doi:10.1007/s11433-011-4564-x`

[3] Tao Wei and Q. Qin, "Design of the two-stage collimation system for CSNS/RCS", *Nucl. Instrum. Methods*, vol. 566, pp. 212-217, 2006. `doi:10.1016/j.nima.2006.06.069`

[4] "Preliminary design report for China Spallation Neutron Source", Institute of High Energy Physics, Feb. 2016.

[5] A. Shishlo, S. Cousineau, J. Holmes, and T. Gorlov, "The particle accelerator simulation code PyORBIT", *Procedia Comput. Sci.*, vol. 51, pp. 1272-1281, 2015. `doi:10.1016/j.procs.2015.05.312`

[6] S. Xu *et al.*, "Beam commissioning and beam loss control for CSNS accelerators", *J. Instrum.*, vol. 15, p. P07023, Jul. 2020. `doi:10.1088/1748-0221/15/07/P07023`