

STUDIES ON MOMENTUM COLLIMATION FOR CSNS-RCS UPGRADES

Yuwen An^{1*}, Jianliang Chen¹, Shouyan Xu¹, Yuan Yue¹, Xiaohan Lu¹, Jiebing Yu¹
Institute of High Energy Physics, Chinese Academy of Sciences (CAS), Beijing, China
¹also at Spallation Neutron Source Science Center, Dongguan, China

Abstract

The CSNS project is a high intensity pulsed facility with the repetition rate of 25 Hz, and achieved the design goal of 100 kW in March 2020. The upgrades of the CSNS are proposed, including a 200 kW and 500 kW upgrades scheme. Due to the high intensity of the proton beam of the upgrades, the bunching factor should be increased to alleviate the space charge effects, and the momentum collimator is a reasonable choice to absorb the beam halo occurred in the arc region of the RCS. This paper will show the design scheme of the momentum collimator and the simulation results are also presented.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is a multi-discipline research platform [1-4] located in the southern of China, Dongguan, Guangdong province. The accelerator consists of an 80 MeV hydrogen Linac and a 1.6 GeV Rapid Cycling Synchrotron (RCS). The hydrogen beam was accelerated to 80 MeV by four DTL tanks, stripped by the carbon foil and accelerated by the RCS to 1.6 GeV. The CSNS passed its national acceptance in March 2018 with the beam power of 10 kW. And after two years of the commissioning, the beam power was increased steadily, and reached 100 kW in March 2020.

The accelerator upgrades plan was proposed. The aims of the upgrades were 200 kW and 500 kW, corresponding to RCS upgrade and super conductive Linac upgrade respectively. The Kinetic energy still fixed at 1.6 GeV while the kinetic energy of the Linac were 80 MeV and 300 MeV. Because of the high intensity increased of the upgrades, the space charge effects were more serious. An effective approach is to increase bunching factor of the beam to alleviate the space charge effect, and it may make the beam halo lost in the arc region of the RCS. The momentum collimation is a reasonable approach and the beam halo can be located in the area of the momentum collimator. This paper will show 200 kW beam dynamics and 500 kW beam dynamics. The comparison of single stage collimation scheme and two stage collimation scheme was also done. Table 1 shows the upgrades schemes of the CSNS.

BEAM DYNAMICS OF THE CSNS UPGRADES

200 kW Beam Dynamics

The aim of the 200 kW upgrade is to increase beam intensity from 1.56×10^{13} to 3.2×10^{13} , and the space charge may

* anyw@ihep.ac.cn

Table 1: Upgrades Schemes of the CSNS

	CSNS I	CSNS 200 kW Upgrades	CSNS II
Beam power	100	200	500
Repetition Rate [Hz]	25	25	25
Inj. Energy [MeV]	80	80	300
Ext. Energy [GeV]	1.6	1.6	1.6
Beam Intensity [$\times 10^{13}$]	1.56	3.12	7.8
Harmonic number	2	4	4

become a serious effect. As for a uniform round distribution beam, the incoherent tune shift due to the space charge effect can be written as follows [2]

$$\Delta \nu = \frac{-Nr_0}{4\pi \epsilon_{rms} B_f \beta^2 \gamma^3}, \quad (1)$$

where N is the particle numbers, r_0 is the classical radius of the proton, ϵ_{rms} is the beam emittance, β and γ are the lorentz factors. The simulation of 200 kW beam dynamics is studied by PyORBIT code [5]. Figure 1 shows the tune shift due to incoherent space charge effects at 200 kW. Figure 2 shows the beam emittance evolution at 200 kW. The maximum beam emittance is about $440 \pi \text{ mm-mrad}/360 \pi \text{ mm-mrad}$ (H/V) for 99% emittance near about 1~2 second. Figure 3 shows the beam loss distribution along the ring, and the most beam occurred in the arc region of the RCS.

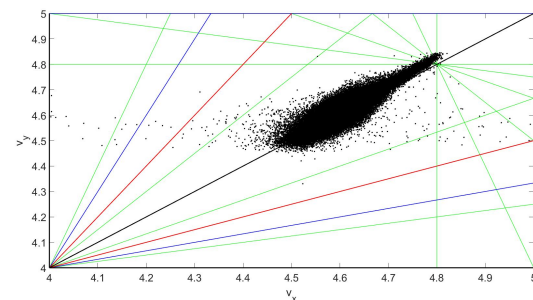


Figure 1: Tune shift due to incoherent space charge effects at 200 kW.

500 kW Beam Dynamics

The proposal of 500 kW upgrades, also known as CSNS II, aims to deliver more intensity beam, was accepted in 2021. The upgrades include a super conductive cavity accelerating hydrogen beam to 300 MeV, and dual harmonic cavities to enlarge longitudinal acceptance. The upgrade is to increase

beam intensity from 1.56×10^{13} to 7.8×10^{13} . Figure 4 shows the emittance evolution at 500 kW, and the maximum beam emittance is about $180 \pi \text{mm-mrad}/260 \pi \text{mm-mrad}$ (H/V) for 99% emittance near about 2~3 second.

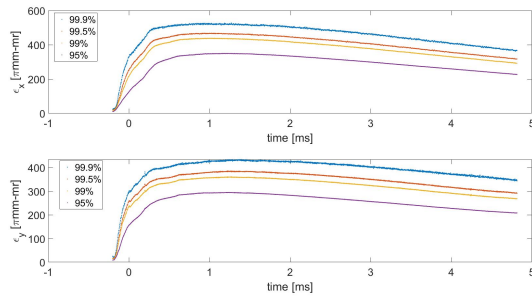


Figure 2: Beam emittance evolution at 200 kW. The blue line, the red line, the yellow line and the purple line represent 99.9%, 99.5%, 99% and 95% respectively.

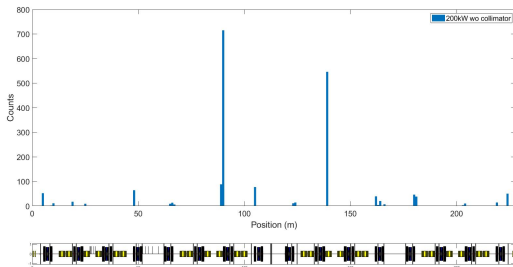


Figure 3: Beam loss distribution along the ring. The yellow box at the bottom represent the dipoles.

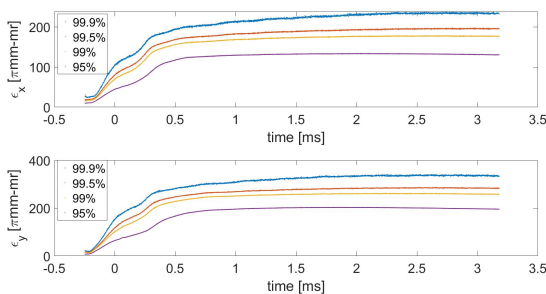


Figure 4: The emittance evolution at 500 kW. The blue line, the red line, the yellow line and the purple line represent 99.9%, 99.5%, 99% and 95% respectively.

Bunching Factor Comparison

The bunching factor is defined as the ratio of the average current to the peak current. High bunching factor may alleviate the space charge effect. However, the beam may loss in the arc region because of the momentum aperture limit of the accelerator. Figure 5 shows the bunching factor comparison of different beam power. As for 100 kW, the bunching factor of the beam decreased steadily from 0.27. The bunching factor may exceed 0.47 due to adopting dual harmonics cavities.

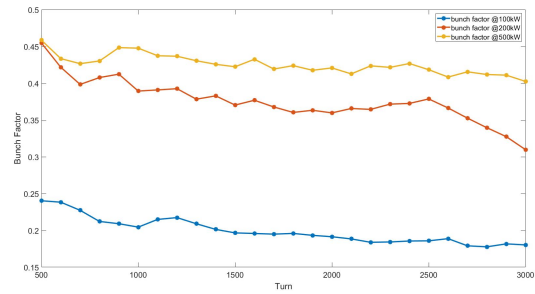
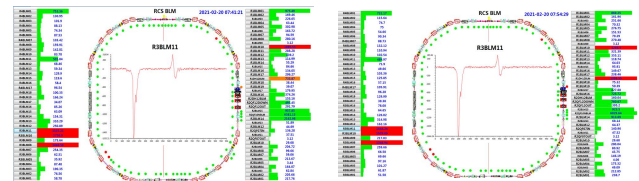


Figure 5: Bunching factor comparison. The blue line, the red line and the yellow line represent 100 kW, 200 kW and 500 kW respectively.

EXPERIMENTS CARRIED OUT IN CSNS 100 KW

Beam loss in the arc region should be located at the collimation region for protecting the machine and safety maintenance. It is very useful to investigate the efficiency of the betatron collimation system. Beam loss was occurred in the arc region by tuning the debunch in the Linac to Ring Beam Transport Line (LRBT). Figure 6 shows the betatron collimation efficiency. By using betatron collimator, the beam loss in the arc region still existed while the transmission rate of the beam decreased very obvious as the shrink of the betatron collimator. The experiment may demonstrate that the betatron collimator had little effect in clean the longitudinal halo.



(a) Beam loss distribution without betatron collimator. (b) Beam loss distribution with betatron collimator.

Figure 6: Betatron collimation efficiency.

COLLIMATION SCHEME

Since the betatron collimator had little effect to clean beam halo in the longitudinal plane, it may be a reasonable choice to implement momentum collimator to absorb the beam halo in the arc of the ring. In general, the collimation scheme often designed as single stage collimation or multistage collimation region.

Single Stage Collimation Scheme

Single stage collimation system that intercepts beam losses by placing a primary collimator to the beam halo [6]. Figure 7 shows single stage collimator, and the collimation efficiency can reach above 80% with copper. The collimation efficiency can still be raised by adopt other materials, that will be shown in the following section.

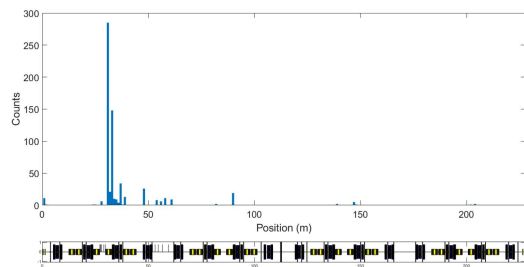


Figure 7: Single stage momentum collimator scheme at the CSNS/RCS.

Two Stage Collimation Scheme

Unlike single stage collimator, the two stage collimation systems using a scrapper as the primary collimator to scatter the halo beam, and the betatron collimator in the drift section may be used to absorb the scattered particles. Figure 8 shows two stage collimation scheme. The collimation efficiency seems a little smaller than single stage collimation. As a medi-scale accelerator, the phase advance between the scrapper and the absorber can not be chosen very freely.

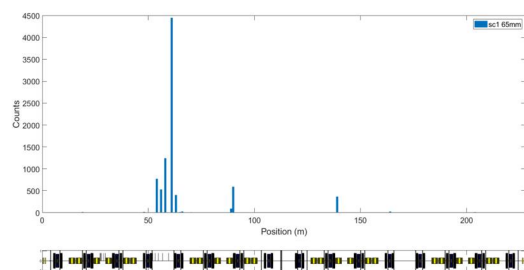


Figure 8: Two stage collimation scheme.

Material Effects of the Collimator

The beam interacts with material may be summarized as ionization, coulomb scattering, inelastic scattering, elastic scattering and so on. It is very useful to investigate the collimation efficiency related to the material. In the simulation, the comparison among 9 kinds of materials were studied in the frame of the single stage collimation, and the length of the material is set to 2 m. The material includes carbon, aluminum, iron, copper, tantalum, tungsten, platinum, lead, and black absorber. Figure 9 shows the collimation efficiency comparison from different materials. The collimation efficiency of the carbon is the lowest, about 65%, while the lead and black absorber can reach above 97%. Despite the collimation efficiency of the copper is not the very highest, the copper still is the primary option.

CONCLUSION

CSNS upgrades to 200 kW and 500 kW may bring about high intensity of the beam, about 2 times or 5 times to the present status, and that will lead to high serious space charge effects. In order to mitigate space charge effects, an effective approach of increasing bunching factor is adopted.

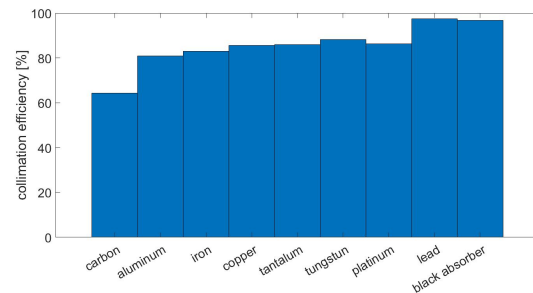


Figure 9: Collimation efficiency comparison from different materials.

Increasing bunching factor may lead to beam loss in the arc region. The experiment studied in CSNS shows there is little effect for betatron collimator to absorb the beam halo. The momentum collimator may be a reasonable choice for absorbing the beam halo in the arc region.

As for a preliminary study, the study shows that momentum collimator is effective for absorb the beam halo, and it is very useful for CSNS upgrades. The effects of material is carefully compared for future use. One stage collimation and two stage collimation are also carefully studied for future choice.

ACKNOWLEDGEMENTS

The author would like to thank Professor Y. Irie and Professor K. Yamamoto for sharing momentum collimator commissioning at J-PARC, and Professor C. Worsop for his discussion of ISIS collimators.

REFERENCES

- [1] S. Wang, S. X. Fang, Q. Qin, J. Y. Tang, and J. Wei, "Introduction to the overall physics design of CSNS accelerators", *Chinese Physics C*, vol. 33, no. S2, pp. 1–3, Jun. 2009. doi:10.1088/1674-1137/33/s2/001
- [2] J. Wei *et al.*, "China Spallation Neutron Source – an overview of application prospects", *Chinese Physics C*, vol. 33, no. 11, pp. 1033–1042, Nov. 2009. doi:10.1088/1674-1137/33/11/021
- [3] H. Chen and X. Wang, "China's first pulsed neutron source", *Nature Materials*, vol. 15, pp. 689–691, 2016. doi:10.1038/nmat4655
- [4] S. Wang, Y. W. An, S. X. Fang, *et al.*, "An overview of design for CSNS/RCS and beam transport", *Science China Physics, Mechanics and Astronomy*, vol. 54, no. S2, pp. 239–244, Nov. 2011. doi:10.1007/s11433-011-4564-x
- [5] A. Shishlo, S. Cousineau, J. Holmes, and T. Gorlov, "The Particle Accelerator Simulation Code PyORBIT", *Procedia Computer Science*, vol. 51, pp. 1272–1281, 2015. doi:10.1016/j.procs.2015.05.312
- [6] S. Redaelli, "Beam Cleaning and Collimation Systems", in *Proc. 2014 Joint Int. Accelerator School: Beam Loss and Accelerator Protection*, Newport Beach, US, Nov. 2014, pp. 403–437. doi:10.5170/CERN-2016-002.403