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# STUDIES ON MOMENTUM COLLIMATION FOR CSNS-RCS UPGRADES

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*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 occured 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 multicipline 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 commisssioning, 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 reaonable 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 comparsion of single stage collimation scheme and two stage collimation scheme was also done. Table 1 shows the upgrades schemes of the CSNS.

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 [$*10^{13}$]** | 1.56 | 3.12 | 7.8 |
| **Harmonic number** | 2 | 4 | 4 |

## 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 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]

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

where $N$ is the particle numbers, $r_0$ is the classical radius of the proton, $\varepsilon_{rms}$ is the beam emittance, $\beta$ and $\gamma$ are the lorentz factors.The simulation of 200 kW beam dynamics is studied by PyORBBIT 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 $\pi$mm-mrad/360 $\pi$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 occoured in the arc region of the RCS.

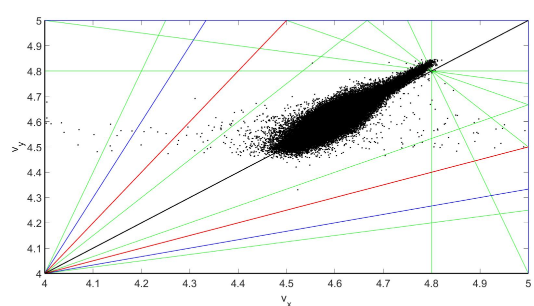


Figure 1: Tune shift due to incoherent space charge effects at 200 kW.

### *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

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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 $\pi$mm-mrad/260 $\pi$mm-mrad (H/V) for 99% emittance near about 2~3 second.

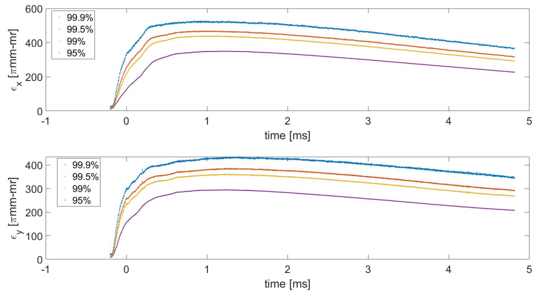



Figure 2: Beam emittance evolution at 200 kW. The blue line, the red line, the yellow line and the purple line represent 99.9%, 99.5%, 99% and 95% respectively.

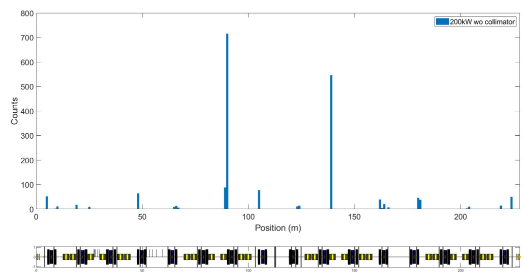



Figure 3: Beam loss distribution along the ring. The yellow box at the bottom represent the dipoles.

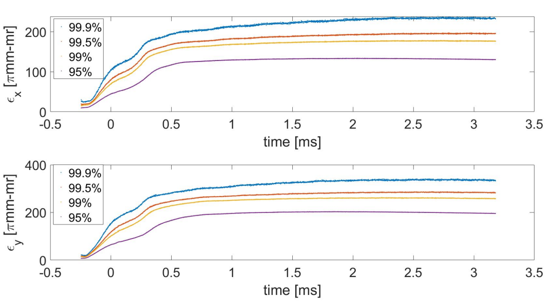



Figure 4: The emittance evolution at 500 kW. The blue line, the red line, the yellow line and the purple line represent 99.9%, 99.5%, 99% and 95% respectively.

### *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 comparsion 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.

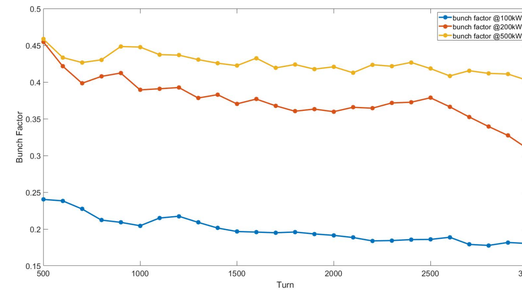
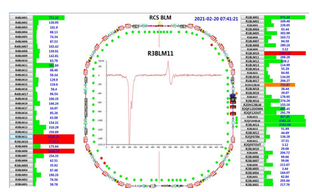


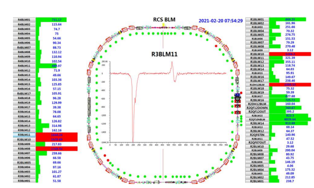

Figure 5: Bunching factor comparison. The blue line, the red line and the yellow line represent 100 kW, 200 kW and 500 kW respectively.

## 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 maintainance. It is very useful to investigate the efficiency of the betatron collimation system. Beam loss was occured 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 transmition 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.

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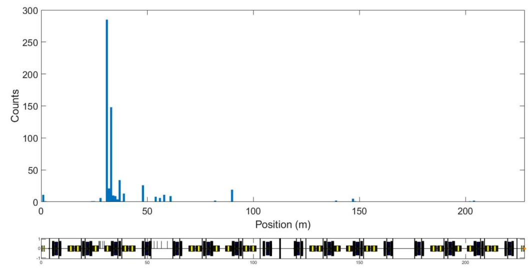


Figure 7: Single stage momentum collimator scheme at the CSNS/RCS.

### *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 effiency seems a little smaller than single satge collimation. As a medi-scale accelerator, the phase advance between the scrapper and the absorber can not be choosen very freely.

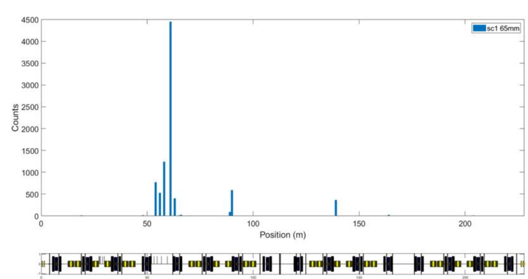


Figure 8: Two stage collimation scheme.

### *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 effiency related to the material. In the simulation, the comparison ammong 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 includs carbon, aluminum, iron, copper, tantalum, tungstun, platinum, lead, and black absorber. Figure 9 shows the collimation efficiency comparison from different materials. The collimation effiency of the carbon is the lowest, about 65%, while the lead and black absorber can reach above 97%. Despite the collimation effiency of the copper is not the very highest, the copper still is the primary option.

## CONCLUSION

CSNS upgrades to 200 kW and 500 kW my 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 mitigrade space charge effects, an effective approach of increasing bunching factor is adopted.

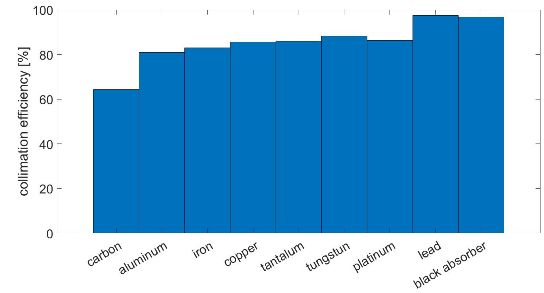


Figure 9: Collimation efficiency comparison from different materials.

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.

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