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LOCAL ORBIT CORRECTION APPLICATION FOR CSNS-RCS HIGH INTENSITY COMMISSIONING

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Abstract

The China Spallation Neutron Source (CSNS) is a high intensity hadron pulse facility which achieved the design goal in March, 2020. The Rapid Cycling Synchrotron (RCS) is the important part of the CSNS which accelerates the proton beam from 80 MeV to 1.6 GeV. During the high intensity commissioning of the RCS, an local orbit correction application was developed. Because of the good performance of the local orbit controlling at the ramping stage, the beam loss was optimized effectively in the process of the acceleration. In the paper, the efficiency of the beam loss optimization during the acceleration is given and the future plans were proposed.

INTRODUCTION

The China spallation Neutron Source (CSNS) [1-4] is a high intensity hadron pulse facility with the repetition rate of 25 Hz which aims to provide 100 kW proton beam at the first stage. The accelerator consists of an 80 MeV negative hydrogen Linac and a 1.6 GeV Rapid Cycling Synchrotron (RCS). The negative hydrogen beam is stripped to the proton beam and then injected into the RCS with the carbon foil. The proton beam is accelerated and accumulated to 1.6 GeV at RCS and then struck on the tungsten target. The beam commissioning of the RCS began from 2017, and the beam power is raised steadily in the following three years. At the high intensity beam commissioning, especially at 80 kW and 100 kW beam commissioning, a novel local orbit correction method is adopted to increase the beam transmission rate and control the beam loss at RCS.

It is a tough journey for CSNS high intensity beam commissioning, and many aspects of the accelerator are carefully optimized, such as RF capture for larger bunch factor, injection painting for a reasonable emittance growth, working point investigation for avoiding the resonance lines. In order to alleviate the resonance effects caused by space charge, the working point investigation is crucial for high beam intensity commissioning. For better controlling of the beam loss, a novel orbit correction program based on accelerator toolbox [5] is developed to correct the orbit at each trace of the orbit.

DESCRIPTION OF THE RCS ORBIT CORRECTION SYSTEM

The RCS of the CSNS is a key part of the accelerator which accelerates the beam from 80 MeV to 1.6 GeV with the repetition rate of 25 Hz. 24 dipoles and 48 quadrupoles constitute a four folds super-period lattice based on the triplet structure. 17 horizontal correctors and 17 vertical correctors are used to correct the beam orbits at the 32 BPMs. As a rapid cycling synchrotron, the mismatch between magnets and RF cavities in the process of ramping can make the optics deteriorated from that of the design. And the magnetic field discretization of the 24 dipoles of the RCS can also lead to the orbit variation in the whole cycle. For better control of the beam orbit in one cycle, generally the orbit is often split into many traces. There are 20 orbit traces in one cycle corresponding to the ramping time 20 milliseconds, and the correctors with programmed power supplies can be used to correct every trace of the orbit at each second. Figure 1 shows the global orbit corrections applied at CSNS-RCS. The 20 traces of the horizontal orbit are corrected from ±15 mm to ±6 mm, and the 20 traces of the vertical orbit are corrected from ±15 mm to ±3 mm [6].

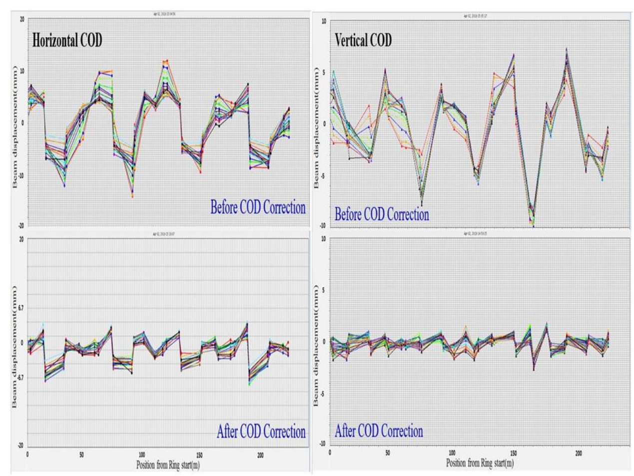

Figure 1: Global orbit corrections applied at CSNS/RCS. Upper: 20 traces of the horizontal/vertical orbit before correction. Bottom: 20 traces of the horizontal/vertical orbits after correction.

It is hard to correct the orbit traces to the golden orbit traces for the global orbit correction because of the inaccuracy of optics as well as BPM offsets in the RCS. The golden orbit traces can be defined as the orbit traces with high beam transmission rate and low beam loss. Fortunately, after a series of beam commissioning, the optics of the RCS can be controlled more precisely. Based on the precise control of the optics, the novel local orbit correction can be used to tune the correctors at every orbit trace to get the high beam transmission rate and low beam loss. The local orbit cor-

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rection is a very useful approach to tune the orbits at some special areas while the orbits at other areas are not changed. Two-corrector with the right phase advance can be used to form a local orbit correction in theoretically. However, three-corrector and four-corrector are often used to correct local orbits in beam commissioning. Due to the flexibility at local orbit correction, four-corrector is more widely used. In four-corrector local bump scheme, the relationship between BPMs and correctors can be wrote as follows

$$\sqrt{\beta_3}\theta_3 = -\frac{\sqrt{\beta_1}\theta_1 sin\psi_{41} + \sqrt{\beta_2}\theta_2 sin\psi_{42}}{sin\psi_{43}}, \quad (1)$$

$$\sqrt{\beta_4}\theta_4 = -\frac{\sqrt{\beta_1}\theta_1 sin\psi_{31} + \sqrt{\beta_2}\theta_2 sin\psi_{32}}{sin\psi_{43}}, \quad (2)$$

where $\theta_i = \frac{(\int B\,dl)_i}{B\rho}$ (i = 1, 2, 3, 4) is the kick angle, β_i is the beta function at the *i*-th corrector, and ψ_{ij} is the phase advance from *j*-th corrector to *i*-th corrector.

For high intensity beam commissioning, the hadron accelerators may choose a transverse tune variation scheme to optimize the ring's performance. For example, the transverse tune varies dynamically during the 10-ms cycle in the ISIS synchrotron cycle [7]. The variation tune scheme in the ISIS is used to compensate natural chromaticity, minimize space charge effects, avoid transverse resistive wall instability and avoid coupling resonance. In CSNS/RCS high intensity beam commissioning, the transverse tunes are carefully studies to minimize the space charge effects and coupling resonance. Figure 2 shows the tune variation in one cycle at the CSNS/RCS, from 4.80/4.87 (H/V) to 4.77/4.77 (H/V).

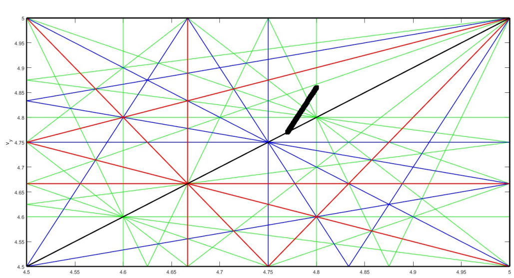

Figure 2: Tune footprint in one cycle at the CSNS/RCS.

Because of the transverse tune variation scheme is adopted in high intensity beam commissioning at CSNS/RCS. The beta functions and phase advances are also varied in the 20-ms cycle. The novel local orbit correction method takes these effects into considerations and corrects the orbit in each trace with the synchronized optics. The novel local orbit correction is an APP based on accelerator toolbox in Fig. 3. This APP contains three parts. From the left part, the suitable correctors should be chosen near the BPM at which the orbit will be corrected. At the center part, the magnetic fields which should be changed will be calculated according to the corrector's strength, and by using the excitation curve between corrector's magnetic field and current, and the current will be set to the correctors. The predicted orbit changes are given at the right part. The effect of the varied lattice in one cycle is contained in the calculation package at the center part. The power supplies of the correctors can be programed with the step of 1ms in one cycle. At the bottom of the APP, the start and the end mean the period of the power supplies should be changed.

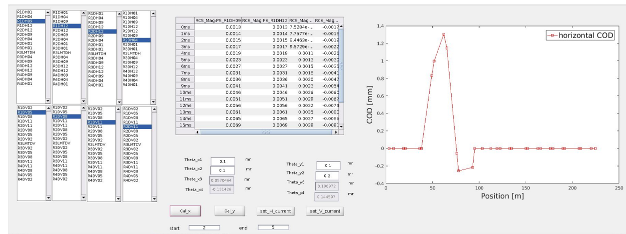

Figure 3: Local orbit correction APP developed for CSNS/RCS commissioning.

100 kW BEAM COMMISSIONING BASED ON LOCAL ORBIT CORRECTION

After the beam power of CSNS achieved 80 kW, the beam commissioning approaches are more flexible. In 100kW beam commissioning, the local orbit correction is often combined with collimator optimization for a higher beam transmission rate and lower beam loss rate. After a series iteration and optimization of the orbit, the beam transmission rate will grow and the beam loss will be minimized. Take the R2BLM05 for example, a detailed optimization procedure is reviewed as follows.

1. Find the neighbor BPMs of the R2BLM05, and the R2BPM01 and R2BPM02 are the neighbor BPMs of the R2BLM05.
2. Find the four correctors that could form a local orbit scheme. The correctors (R3LMTDH, R3DH01, R2DH01, and R2DH04) could meet the requirements.
3. Change the strength of these four correctors with a small step by the novel local orbit correction APP and compare the intensity strength at the R2BLM05.
4. Choose the best results and then optimize the next BLM.

Figure 4 shows the 20 horizontal orbit traces comparison at the 32 BPMs before and after local orbit correction. The red circle represents the orbit traces before orbit correction while the blue square represents the orbit traces after orbit correction. The orbits at the R2BPM01 and the R2BPM02 from trace1 to trace6 are changed while from trace7 to trace20 are kept. The orbits at other BPMs in the whole cycle are kept well. That means the orbits localized very well. Actually, the emittance of the beam will be decreased after 4ms, so generally the first 6 traces are only focused.

Figure 5 shows the beam loss intensity optimization at R2BLM05. On the left of the Fig. 5, the waveform [8] of the R2BLM05 is clearly shown. The beam loss occurs when the

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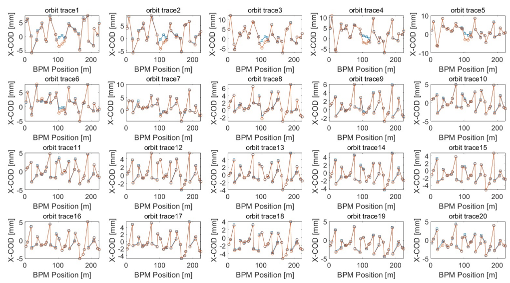

Figure 4: The horizontal orbits for 20 traces. The red circle represents the orbits before correction and the blue square represents the orbits after correction.

waveform goes down and the beam loss is terminated when the waveform gets the maximum value. So the beam loss at the R2BLM05 lasted from around 1 ms to 4 ms. By applying the local orbit correction, the beam intensity waveform at R2BLM05 is show on the right of the Fig. 5. The maximum beam loss intensity at the R2BLM05 is 9488 before local orbit correction and that is minimized to 255 after local orbit correction. The waveform of the R2BLM05 in the second half is due to signal interference and the problem may be fixed in the future commissioning of the RCS.

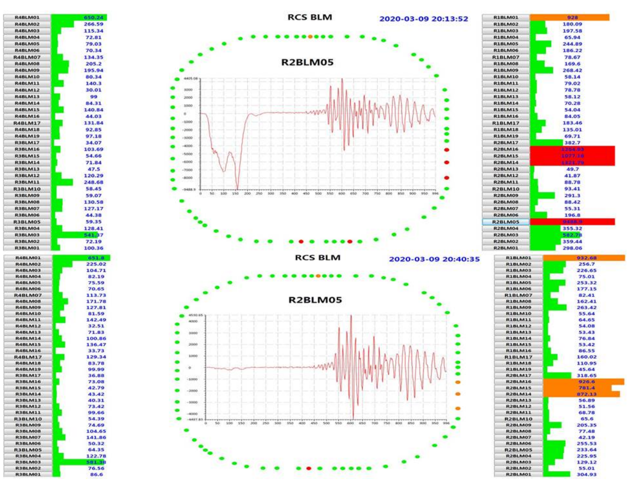

Figure 5: R2BLM05 beam loss optimization. Upper: the waveform of the R2BLM05 before correction; Bottom: the waveform of the R2BLM05 after correction.

Figure 6 shows the beam transmission rate comparison of the RCS. The beam transmission rate is calculated by DCCT [9]. The waveform of the DCCT contains around 3000 points and the width of the waveform is around 30 ms. The transmission rate is defined as the ratio of the number of the extraction particles to the number of the injection particles. The number of injection particles is taken at around the 50th point, namely 0.5 ms after injection, and the number of the extraction particles is taken at around near the 2000th point. Figure 6 is the result from single shot mode, and before the correction the transmission is around 96.18% while the transmission rate can be raised to 96.86% after correction. Actually, this picture just shows the R2BLM05 optimization. And in high beam intensity commissioning, after a series of optimization and iteration applied on many BLMs, the local orbit correction can contribute more than 1% to the transmission rate.

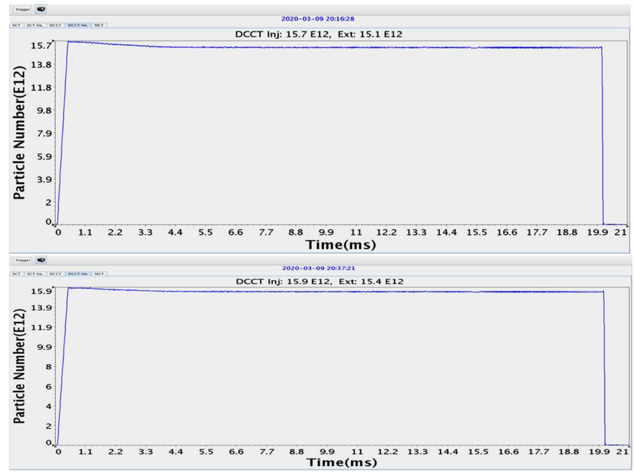

Figure 6: The comparison of the transmission rate of the RCS. Upper: the transmission rate is around 96.18% before correction; Bottom: the transmission rate is around 96.86% after correction.

CONCLUSION

In order to mitigate the resonances which may cause space charge effects and collective instability, the tunes of the RCS is varied in one cycle. The optics of the RCS is well calibrated and the optics agreed well with that of the designed. Embedding the effects of the lattice variation in one cycle, a novel local orbit correction APP with the frame of accelerator toolbox is developed to optimize the beam transmission rate and minimize the beam loss. After a series of optimization and iteration applied to many BLMs, the beam loss is optimized well, and the beam transmission rate can be raised above 1 percent. Two factors may be summarized as follows. A rigorous constraint applied on the local bump area and very little orbit leakage can be used to find the golden orbit with the careful scan method. And also at the collimation area, the optimization of the beam directions may be better for the absorber of the secondary collimators.

The novel local orbit correction is well used for the CSNS/RCS commissioning, and the potentialities may be excavated more deeply with the upgrade of the correctors of the CSNS in the future.

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