# PREPARATION FOR THE CSNS-RCS COMMISSIONING*

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*Abstract*

As a key part of the China Spallation Neutron Source (CSNS) Project, the Rapid Cycling Synchrotron (RCS) accumulates and accelerates the proton beam from 80MeV to 1.6GeV for extracting and striking the target with a repetition rate of 25Hz. As a commissioning plan, the BPM offset should be carefully investigated before closed orbit distortion (COD) correction. The fast response correctors are installed to correct orbit distortion and model the lattice of the RCS in every 1ms period. The bunch-by-bunch data from BPMs are collected and decomposed for better known of the RCS Lattice.

## INTRODUCTION

The CSNS accelerator consists of a low energy $H^-$ Linac and a rapid cycling proton synchrotron. The installation of the accelerator is completed, and the beam commissioning is in progress. Due to the klystron malfunction of one of the DTL Tank, the Linac can provide 10mA $H^-$ beam in the energy of 60MeV, and the beam transport efficiency in the Linac can reach 90%. And the next stage of beam commissioning is to inject the beam to the ring, and ramp the beam in the RCS from 60MeV to 1.6GeV with the repetition rate of 25Hz. In this stage, orbit correction and lattice modelling can be done carefully and after the klystron of the DTL4 is fixed, the proton can be ramped from 80MeV to 1.6GeV. The RCS has 48 quadrupoles magnets (8 each for 4 groups of focusing quadrupoles and 16 defocusing quadrupoles powered by one power supply) powered by 5 power supplies, and 32 BPMs. It has 32 steering dipole magnets (16 each for horizontal and vertical) in order to perform COD correction. Table 1 shows the main parameters of RCS [1].

Table 1: Main Parameters of RCS

| Parameters | Units | Values |
|---|---|---|
| Circumference | m | 227.92 |
| Repetition Rate | Hz | 25 |
| Inj. & Ext. Energy | MeV | 80/1600 |
| Beam Power | kW | 100 |
| Quad | | 48 |
| Dipole | | 24 |
| Corrector | | 16/16 |
| BPM | | 32/32 |
| Nominal Tunes(H/V) | 1 | 4.86/4.78 |

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To meet the goal of beam commissioning of the RCS, the primary simulation such as BPM offset measurement, orbit correction, and lattice modelling the RCS should be well prepared. And in section II, the simulation of the BPM offset measurements will be carefully shown. Section III depicts the closed orbit distortion correction of the RCS. Section IV devotes the lattice modelling by analysing the BPM bunch by bunch data. The summary and discussion is in the last section.

## BPM OFFSET MEASUREMENT

BPM is a vital important element in accelerator to investigate the beam parameters. It often provides two kinds of data. One is for COD data and the other is for bunch by bunch data. The COD data can be derived by taking arithmetic mean or taking Fourier analysis of the bunch by bunch data. And for CSNS case, the COD is provided by PV in every 40ms. For a better performance of the COD, the BPM offset should be carefully fixed. Beam based alignment is used for measuring the BPM offset, and usually it calls for independent control of the quadrupole. By scanning the orbit of the BPM near the quadrupole, and one can find the orbit that cannot be disturbed by changing the quadrupoles strength, and that orbit represents the BPM offset. Many accelerator can adopt this technique to get the BPM offset by changing quadrupole individually with different orbit. However, if the quadrupole magnet cannot be changed individually, the measurement of the BPM Offset should be done with a slice modification, and this technique is well used for J-PARC/RCS commissioning [2]. A brief introduction of this technique is reviewed as following.

With a kick $\theta$ at position $j$ , a transverse position $x_i$ of the position $s = s_i$ in the ring is expressed as following

$$x_i = \sum_j R_{ij}\theta_j . \quad (1)$$

Where $R_{ij}$ is the element of the response matrix. If the orbit is not in the centre of the quadrupole, the response in the BPM can be represented as following

$$\delta x_i = \mp\sum_j R_{ij}(x_j - \Delta x_j)\Delta K_j l_j . \quad (2)$$

The orbit in the BPM or in the quadrupole can be represented as $x_j$ , and the BPM offset is represented as $\Delta x_j$ , and $\Delta K_j l_j$ represents the integrated field of the quadrupole. The term minus in the right hand of Eq.2 represents the horizontal response, while the plus in the right hand of Eq.2 represents the vertical response. For a simple case, we consider 8 quadrupole magnets grouped with one power supply and just measure the horizontal BPM offset. And Eq.2 can be represented as the matrix form as following




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$$\begin{pmatrix}\delta x_i^{(1)}\\ \delta x_i^{(2)}\\ \delta x_i^{(3)}\\ \delta x_i^{(4)}\\ \delta x_i^{(5)}\\ \delta x_i^{(6)}\\ \delta x_i^{(7)}\\ \delta x_i^{(8)}\\ \delta x_i^{(9)}\end{pmatrix}=-\begin{pmatrix}x_1^{(1)} & x_2^{(1)} & \cdots & x_8^{(1)} & 1\\ x_1^{(2)} & x_2^{(2)} & \cdots & x_8^{(2)} & 1\\ x_1^{(3)} & x_2^{(3)} & \cdots & x_8^{(3)} & 1\\ x_1^{(4)} & x_2^{(4)} & \cdots & x_8^{(4)} & 1\\ x_1^{(5)} & x_2^{(5)} & \cdots & x_8^{(5)} & 1\\ x_1^{(6)} & x_2^{(6)} & \cdots & x_8^{(6)} & 1\\ x_1^{(7)} & x_2^{(7)} & \cdots & x_8^{(7)} & 1\\ x_1^{(8)} & x_2^{(8)} & \cdots & x_8^{(8)} & 1\\ x_1^{(9)} & x_2^{(9)} & \cdots & x_8^{(9)} & 1\end{pmatrix}\begin{pmatrix}R_{i1}\\ R_{i2}\\ R_{i3}\\ R_{i4}\\ R_{i5}\\ R_{i6}\\ R_{i7}\\ R_{i8}\\ \omega_i\end{pmatrix}\Delta K_j l_j. \quad (3)$$

Where subscript and superscript in $\delta x_i^{(m)}$ mean the index of BPM and which time of the measurement of COD respectively. And $\omega_i$ can be written as following

$$\begin{pmatrix}\omega_1\\ \omega_2\\ \cdots\\ \omega_8\end{pmatrix}=\begin{pmatrix}R_{11} & R_{12} & \cdots & R_{18}\\ R_{21} & R_{22} & \cdots & R_{28}\\ \cdots & \cdots & \cdots & \cdots\\ R_{11} & R_{81} & \cdots & R_{88}\end{pmatrix}\begin{pmatrix}\Delta x_1\\ \Delta x_2\\ \cdots\\ \Delta x_8\end{pmatrix}. \quad (4)$$

Firstly one can do the SVD to the Eq.3 and get $w_i$ and then do the SVD to the Eq.4, and the BPM offset can be fixed. In our simulation, all of the horizontal correctors are changed with random kick to make sure each of the orbit is not the others orbits linear combination. And the result of the BPM offset in the horizontal is shown in Fig. 1. The upper diagram is the comparison of the horizontal BPM offset between simulated and fixed, and the bottom diagram is the error bar in our simulation. And we can find that if we don't consider BPM resolution error and suppose the magnet is identical with the design model, the error bar is within one millimetre.

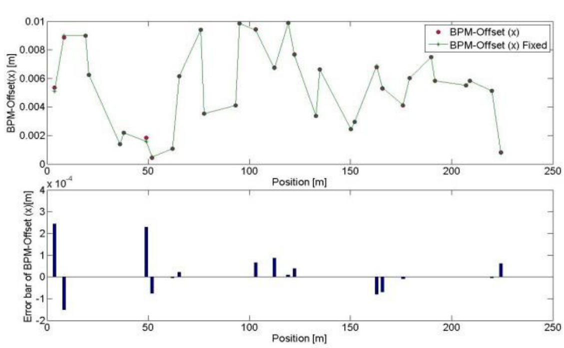


Figure 1: Top: the comparison of horizontal BPM offset between simulated and fixed respectively; Bottom: the error bar of horizontal BPM offset.

## CLOSED ORBIT DISTORTION CORRECTION

The RCS is a Rapid cycling synchrotron with the repetition rate of 25Hz, and the BPM can measure the COD of the beam in every second. Due to magnet field error and misalignment of the dipoles and quadrupoles, as well as the mismatch of the dipoles and quadrupoles in ramping, the COD will be varied in the whole cycle. Thanks to 32 steering magnets (16 each for horizontal and vertical) with programmable power supplies, the COD can be corrected in every 1 millisecond.

In many accelerators, the COD can be corrected by solving response matrix equation with SVD method. However, the RCS use random search method to iterate the live orbit to the predicted orbit because the software of the RCS is based on XAL infrastructure [3]. In our simulation, both the theoretical response matrix and empirical response matrix are used to correct the COD. Figure 2 shows the COD correction performance by using theoretical response matrix. Before COD Correction, the COD may exceed 0.2m both in horizontal and vertical, and after correction, the COD can reach to 1mm.

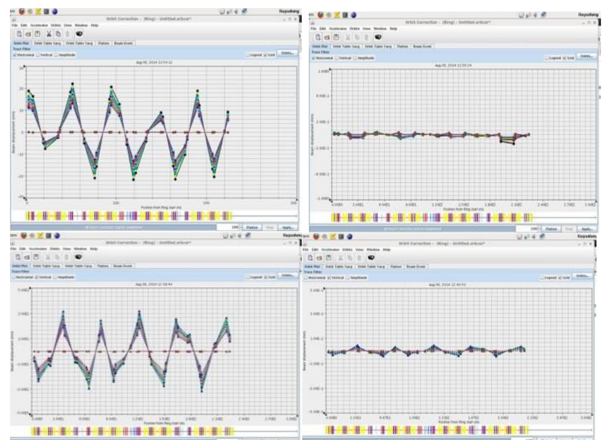

Figure 2: The COD correction performed in RCS. The left two diagrams represent the COD before correction in horizontal and vertical respectively, and the right two diagrams represent the COD after correction in hozi- zontal and vertical respectively.

## LATTICE MODELING WITH BPM BUNCH BY BUNCH DATA

The RCS can provide BPM bunch by bunch data in one T0 (one T0 means one revolution period, and lasts 40ms), 25 times T0 and 250 times T0. The data can be downloaded to NFS server for different purpose. The BPM resolution can be estimated by analysing the bunch by bunch data, otherwise, the lattice parameters can be derived by decomposing the BPM bunch by bunch data. Figure 3 shows the bunch by bunch data of one of the BPM in the RCS [4]. From beam injection to beam extraction, the beam may move around 19630 turns in the RCS. The amplitude of the evolution is decreasing because the energy of the beam ramping from 80MeV to 1.6GeV. The magnet rigidity in the extraction energy is about 6 times in the injection energy, and from our simulation, we found that the amplitude of the evolution at the extraction energy is decreased to 40% of the initial amplitude, which means in the whole cycle, the normalized emmittance of the beam is invariant.

The beam transverse motion is influenced by many physical factors, and the bunch by bunch data of the BPM can provide massive data about the evolution of the beam. The



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data sampled by BPM reflect the beam transverse motion, which is a combination of betatron motion and perturbations from other sources. So, for a simple case, the sampled data can be considered as a linear mixture of a few physical source signals. Many techniques can be used to separate the mixed data into few independent sources [5-7]. However, the Second Order Blind Identification (SOBI) is a suitable choice for us because it is more robust to uncover the coupled signals and the weak signals.

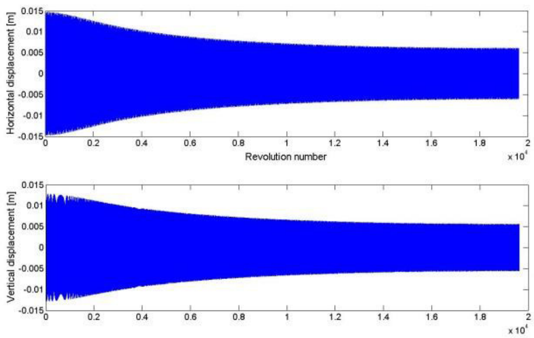


Figure 3: The simulated bunch by bunch data of one BPM. The upper and bottom represent horizontal and vertical respectively.

There are 32 horizontal BPMs and 32 vertical BPMs located in the RCS. All of the data recorded by BPMs can be decomposed to reconstruct the beta function of the lattice. Figure 4 shows the beta functions decomposed by SOBI. If one just has interested in one period in the whole cycle, the SOBI can also get the beta functions in that period.

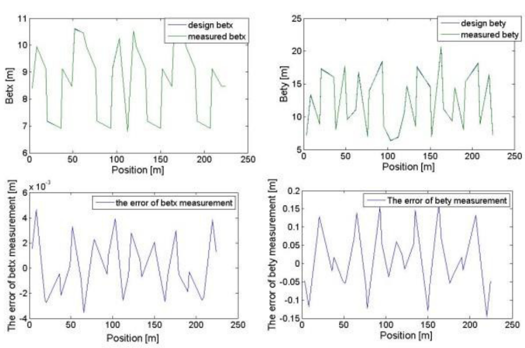


Figure 4: Beta functions decomposed by SOBI. Two graphs at the top represent the horizontal and vertical beta function respectively; and two graphs at the bottom represent the beta-beating in horizontal and vertical re- spectively.

We found that the beta-beating in vertical is much larger than that of horizontal, and the vertical tune decreased from 4.8018 to 4.7811. That is because the strength of the bump magnet used to provide a fixed orbit for the injection beam will be decreased because the particle momentum is increasing.

Figure 5 shows the tunes footprints in one cycle of the RCS ramping in a fourth order resonance diagram. And one can found that although the vertical tune varied in the one cycle, the tune did not cover any resonance line.

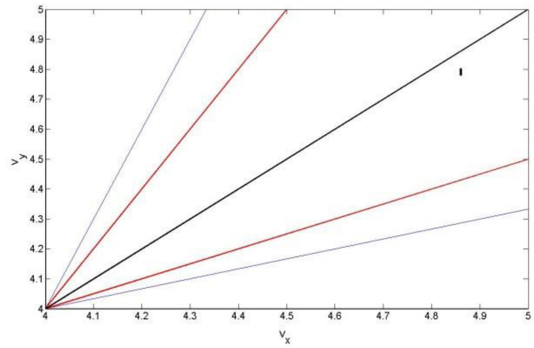


Figure 5: The tunes footprints in the RCS ramping.

## SUMMARY AND DISCUSSION

The commissioning of CSNS is in progress, and the preparation of beam commissioning of CSNS was done. The BPM offset measurement with grouped control quadrupoles has been verified by simulation, and the closed orbit distortion correction in whole cycle was tested in XAL infrastructure. The BPM bunch by bunch data was sampled and decomposed to restore the linear lattice parameters of RCS. With the project going on, more errors will be considered in the simulation to discover the malfunction of the accelerator elements.

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