COMBINE EFFECTS OF SPACE CHARGE AND CHROMATICITY SEXTUPOLES AT CSNS/RCS *

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Abstract

Most high current proton synchrotrons, such as The Rapid Cycling Synchrotron (RCS) of The China Spallation Neutron Source (CSNS), are operated under the transition energy, and the natural chromaticity is small. These proton synchrotrons can work without chromatic correction. To reduce the tune spread produced by the chromaticity, chromatic correction is considered by using chromaticity sextupoles for this type of proton synchrotrons, such as J-PARC and SNS. An optimized chromatic correction scheme is proposed for CSNS/RCS. The effects of chromaticity sextupoles on the optical functions are examined. 3-D simulations with and without space charge effects are performed by using the code ORBIT.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is an accelerator-based facility. It consists of a 1.6-GeV Rapid Cycling Synchrotron (RCS) and an 80-MeV linac. RCS accumulates 80 MeV injected beam, and accelerates the 1.56×10^{13} particles to the design energy of 1.6 GeV, and extracts the high energy beam to the target. The lattice of the CSNS/RCS is triplet based four-fold structure. Table 1 shows the main parameters for the lattice [1] [2].

Table 1: Main Parameters of the CSNS/RCS Lattice

Circumference (m)	227.92
Superperiod	4
Acceptance of the Primary Collimators (μπm.rad)	350
Acceptance of the Secondary Collimators (μπm.rad)	400
Betatron tunes (h/v)	4.86/4.78
Natural Chromaticity (h/v)	-4.3/-8.2
Momentum compaction	0.041
RF harmonics	2
Injection energy (MeV)	80
Extraction energy (MeV)	1600
Accumulated particles per pulse	1.56×10^{13}
Trans. acceptance (μπm.rad)	>540

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CHROMATIC CORRECTION SCHEME

There are four long dispersion-free drifts, with the length of 11 meters, for injection, extraction and other elements. The local chromatic correction is not possible. The chromaticity produced in the straight section, where the dispersion is zero, propagates into the main arc, and then is corrected by chromaticity sextupoles located in the arcs [3]. For this type of concentrated chromatic correction, the dependence of the Beta functions on the momentum spread can be enlarged compared with the case without chromaticity sextupoles. To reduce the beta beating with chromaticity sextupoles, chromatic correction scheme is optimized.

Because of the Lattice symmetry along a super period, half a super period is analyzed here. Two families of sextupoles are used in half a super period. The dependence of the Beta functions on the momentum spread along half a super period with chromaticity sextupoles can be expressed as

$$\begin{aligned}\Delta\beta_x(s) &= \frac{\beta_x(s)\Delta p}{2p\sin 2\pi\upsilon_x}\sum_{i=1}^{6}\beta_x(s_i)K(s_i)\cos[2\pi\upsilon_x-2\varphi_{xi}]l_i \\ &-\frac{\beta_x(s)l\Delta p}{2p\sin 2\pi\upsilon_x}(\beta_x(s_1)S_1D_{x1}\cos[2\pi\upsilon_x-2\varphi_{x1}] \\ &+\beta_x(s_2)S_2D_{x2}\cos[2\pi\upsilon_x-2\varphi_{x2}])\end{aligned} \tag{1}$$

$$\begin{aligned}\Delta\beta_y(s) &= -\frac{\beta_y(s)\Delta p}{2\Delta p\sin 2\pi\upsilon_y}\sum_{i=1}^{6}\beta_y(s_i)K(s_i)\cos[2\pi\upsilon_y-2\varphi_{yi}]l_i \\ &+\frac{\beta_y(s)l\Delta p}{2p\sin 2\pi\upsilon_y}(\beta_y(s_1)S_1D_{x1}\cos[2\pi\upsilon_y-2\varphi_{y1}] \\ &+\beta_y(s_2)S_2D_{x2}\cos[2\pi\upsilon_y-2\varphi_{y2}])\end{aligned} \tag{2}$$

where l_i is the quadrupole length, l is the sextupole length. Using Eq. (1) (2), the optimized chromatic correction scheme, the beta beating induced by momentum spread of which is the weakest, is obtained, as shown in Fig. 1.

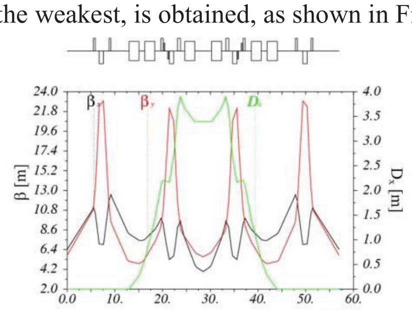

Figure 1: The layout of chromaticity sextupoles along a super period.

EFFECTS ON OPTICAL FUNCTIONS

The dependence of the Beta functions on the momentum spread along a super-period with and without chromatic correction is shown in Fig. 2. It appears that in the case of natural chromaticities there is only a small distortion of the optical functions for particles with nonzero momentum spread, and the distortion of the optical functions is enlarged after chromatic correction.

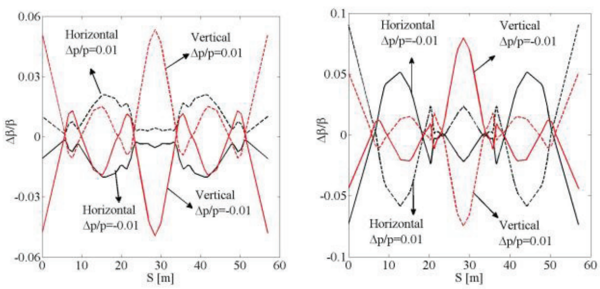

Figure 2: The dependence of the Beta functions on the momentum spread along a super-period with (right) and without (left) chromatic correction ($\Delta\beta=\beta_{\Delta p\neq 0}-\beta_{\Delta p=0}$).

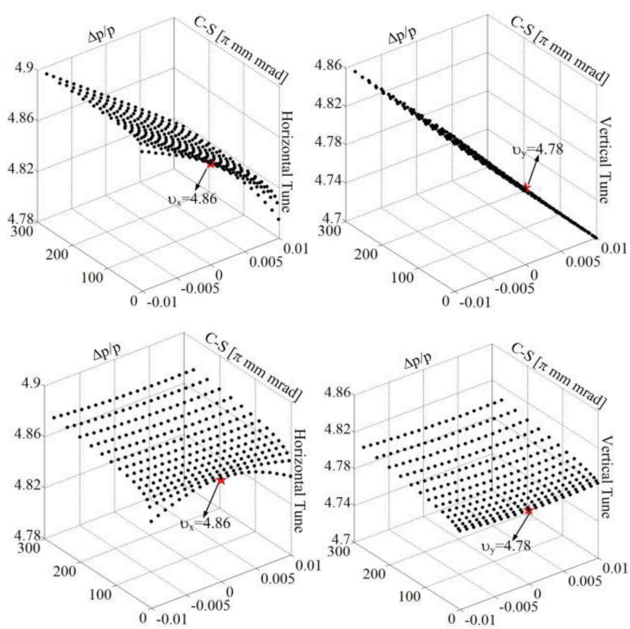

Figure3: Betatron tunes for particles with different momentum spreads and Courant-Snyder (C-S) invariants with (bottom) and without (top) chromaticity sextupoles.

Fig. 3 shows the Betatron tunes, which is obtained by using the code SIMPSONS [4], for particles with different momentum spreads and Courant-Snyder (C-S) invariants with and without chromaticity sextupoles. The tune spread produced by the chromaticity can be apparently reduced by using chromaticity sextupoles. The chromaticity sextupoles are non-linear elements, and can introduce a tune-shift with amplitude [5].

SIMULATION RESULTS

Particles tracking has been performed by using the codes AT and ORBIT [6] without space effects, and the code ORBIT for the case with space charge effects.

In the simulations without space charge effects using AT, the KV distributions with the emittance of 220π-mm-mrad, which is the same as the painted emittance for CSNS/RCS, and 350π-mm-mrad, which is the acceptance of the primary collimitors, are used as the initial distriobution. The simulation results obtained by AT show that the introduction of chromaticity sextupoles, which are non-linear elements, can change the beam distribution, as shown in Fig. 4.

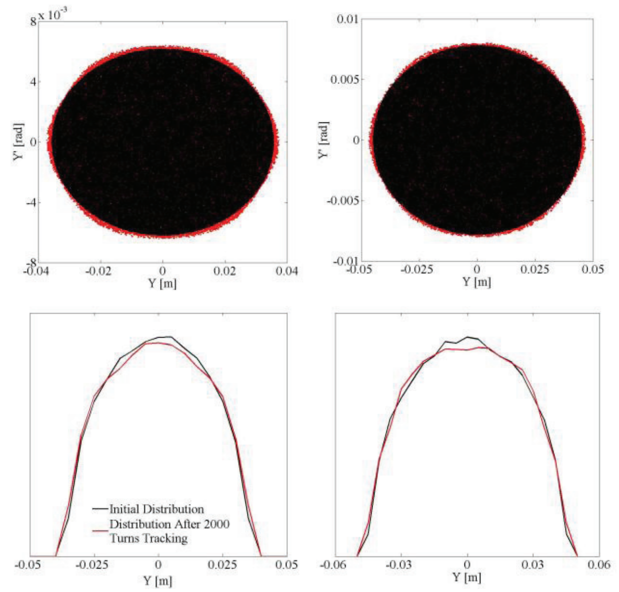

Figure 4: The effects of the chromaticity sextupoles on the beam distribution; the left figures are the simulation results for the case of with the initial emittance of 220π-mm-mrad, and the left figures are the simulation results for the case of with the initial emittance of 350π-mm-mrad; the black dots indicate the initicl distribution, and the red dots indicate the distribution after 2000 turns tracking.

The simulations using code AT are 2-D simutions here. 3-D simulations are also performed by using the code ORBIT with chromaticity sextupoles. Without space effects, there is no obvious emittance growth and no beam loss.

3-D simulations with space charge effects are also performed using ORBIT. At the early stage of acceleration, due to the low energy, space charge effects are the most serious. With the beam acceleration, the beam energy increase, both the space charge effects and beam emittance decrease. Most of the beam loss happens at the early stage of acceleration. 2000 turns beam tracking after injection painting are performed in this paper.

Without chromaticity sextupoles, the total beam loss is less than 0.5% during the 2000 turns tracking, and the collimation efficiency is 91.5%, which means the uncontrolled beam loss is less than 0.05%. For the case with chromaticity sextupoles, 0.6% macro particles are lost during the 2000 turns tracking, and the collimation

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efficiency is 91.7%. Fig. 5 shows the 99% emittance evolutions during acceleration with and without chromaticity sextupoles. The emittance evolution curves are almost the same with and wiout chromaticity sextupoles. The painted emittance with chromaticity sextupoles is larger than the case without chromaticity sextupoles. As shown in 2, the dependence of Beta functions on the momentum spread is enlarged compared with the case without chromaticity sextupoles. The painted distributions are different with and without chromaticity sextupoles using the same injection scheme, as shown in Fig. 6.

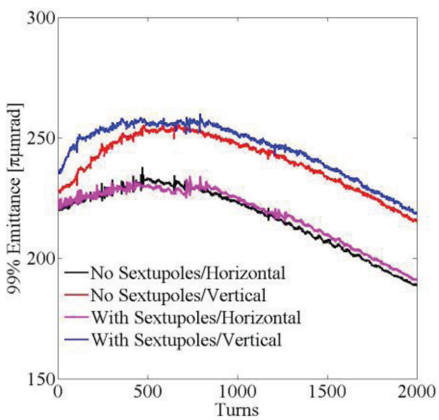

Figure 5: The 99% emittance evolutions during acceleration with and without chromaticity sextupoles.

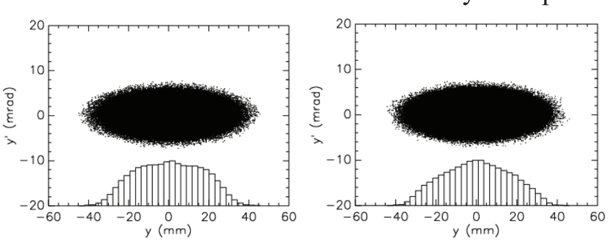

Figure 6: The painted distributions in vertical direction with (right) and without (left) chromaticity sextupoles.

SUMMARY

The optimized chromatic correction scheme, the beta beating induced by momentum spread of which is weak, is proposed for the CSNS/RCS. In the case of natural chromaticities there is only a small distortion of the optical functions for particles with nonzero momentum spread, and the distortion of the optical functions is enlarged after chromatic correction. The chromaticity sextupoles are non-linear elements, and can introduce a tune-shift with amplitude. 3-D simulations are performed by using the code ORBIT. Because the dependence of the Beta functions on the momentum spread is enlarged compared with the case without chromaticity sextupoles, the painted distributions are different with and without chromaticity sextupoles. There are no obvious effects of chromaticity sextupoles on the beam loss and emittance evolutions during acceleration.

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