SPACE CHARGE EFFECTS FOR DIFFERENT CSNS/RCS WORKING POINTS *

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Abstract

The China Spallation Neutron Source (CSNS) operates at 25 Hz repetition rate with the design beam power of 100 KW. CSNS consists of an 80-MeV linac and a 1.6-GeV Rapid Cycling Synchrotron (RCS). Due to the high beam density and high repetition rate for CSNS/RCS, the rate of beam loss must be controlled to a very low level. The major source of beam loss is associated with resonances. Thus, choosing the best suitable working point on the tune diagram is important to reach low beam loss. Different tune areas are explored and compared by considering resonances and the effects of space charge, which can drive particles into the excited resonances. Different working points are simulated and compared by using the codes ORBIT.

INTRODUCTION

The China Spallation Neutron Source (CSNS) is an accelerator-based facility. It operates at 25 Hz repetition rate with the design beam power of 100 kW. CSNS consists of a 1.6-GeV Rapid Cycling Synchrotron (RCS) and an 80-MeV Linac. RCS accumulates 80 MeV injected beam, and accelerates the beam 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].

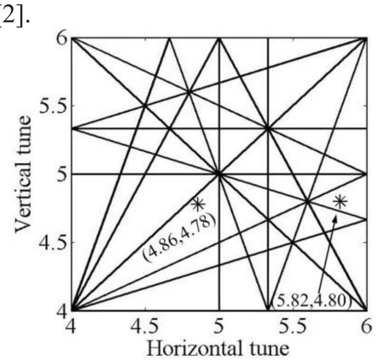

Figure 1: Working points of (4.86, 4.78), (5.82, 4.80) in tune space; up to fourth order structure resonances are shown.

Due to the high beam density and high repetition rate, the rate of beam loss must be controlled to a very low level. The major source of beam loss is associated with resonances. Thus the choice of working points is an important issue. The preferred working point of CSNS/RCS is (4.86, 4.78) which can avoid the major low-order structure resonances, as shown in Fig. 1. However, the tune (4.86, 4.78) is near the Montague resonance $2\upsilon_x$-$2\upsilon_y$=0, which is dangerous for CSNS/RCS [3] [4]. The CSNS/RCS Lattice is flexibly tunable, and the tunes can be matched to integer split-tune (5.82, 4.80), which is immune to the coupling resonance $2\upsilon_x$-$2\upsilon_y$=0. The tune (5.82, 4.80) is simulated and compared with the preferred tune (4.86, 4.78). Different working points near the (4.86, 4.78) are also simulated and compared.

Table 1: Main Parameters of the CSNS/RCS Lattice

Circumference (m)	227.92
Superperiod	4
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
RF Freq. (MHz)	1.0241~2.444
Accumulated particles per pulse	1.56×10^{13}
Trans. acceptance (μπm.rad)	>540
Acceptance of the primary collimators (H/V, μπm.rad)	350
Acceptance of the secondary collimators (H/V, μπm.rad)	400

LATTICE FUNCTION

Table 2 shows the behavior of the maxima of the lattice functions β_x, β_y, D_x and the acceptance for different tunes. Due to the adjustability of the collimator aperture, the acceptance of the primary collimators and the secondary collimators can be adjusted to 350μπm-rad and 350μπm-rad and respectively for all tunes [5].

In the measurements of the prototype quadrupole magnet of CSNS/RCS, it is confirmed that the magnetic field tracking errors between the quadrupoles and the dipoles can be adjusted within 0.1% by compensating by using higher frequency waves. In the actual operations, 8 or 16 quadrupole magnets are powered by the same power supply. Due to the differences between the quadrupole magnets, which are within 0.2% for the same type of quadrupole magnets, the magnetic field tracking errors

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can get up to 0.3%. The simulation results show that the maximum momentum spread can get up to 1% for CSNS/RCS. The dependence of the Lattice functions on the magnetic tracking errors and the momentum spread due to natural chromaticity are examined and compared for different tunes, as shown in Table 2 and Fig. 2. The beta functions are seriously distorted due to the combine effects of natural chromaticity and magnetic tracking error. As shown in Fig. 2, the transverse acceptance is considerably decreased, changing the tune from (4.86, 4.78) to (5.82, 4.80).

Table 2: Comparison of Lattice Functions for Different Working Points

Working points	4.86/4.78	5.82/4.80
Maxima of Beta functions (H/V) [m]	12.6/25.6	12.9/29.0
Maxima of Dispersion functions [m]	3.92	3.03
Acceptance (H/V) [μπm.rad]	570/563	571/497
Natural Chromaticity	-4.3/-8.2	-5.2/-10.2
Maxima of Beta functions considering chromaticity and magnetic tracking errors (H/V) [m]	12.9/27.5	13.5/32.2
Maxima of Chromaticity tune shifts	±0.04/0.08	±0.05/0.1

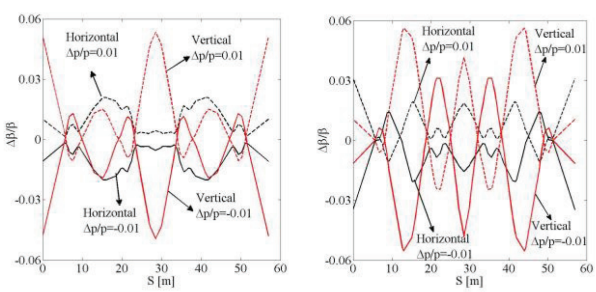

Figure 2: The dependence of the Beta functions on the momentum spread along a super-period for the tunes [4.86, 4.78] (left) and [5.82, 4.4.80] (right).

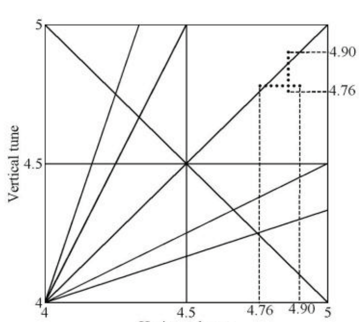

Figure 3: Investigated working points near the tune (4.86, 4.78) in tune space; up to fourth order structure resonances and half integer resonances are shown.

The other working points near the tune (4.86, 4.78), as shown in Fig. 3, are also examined and compared. The simulation results of CSNS/RCS show that the half integer resonance is dangerous, and the space charge tune shift can be up to 0.3. The working points under 5.75 are not considered. Because of the tune shift induced by natural chromaticity and magnetic errors, the working points larger than 4.9 are not investigated. The comparison of the maxima of beta functions and dispersion functions for different working points near the tune (4.86, 4.78) is shown in Fig. 4. The CSNS/RCS Lattice is flexibly tunable near the tune (4.86, 4.78) with the optical functions almost unchanged.

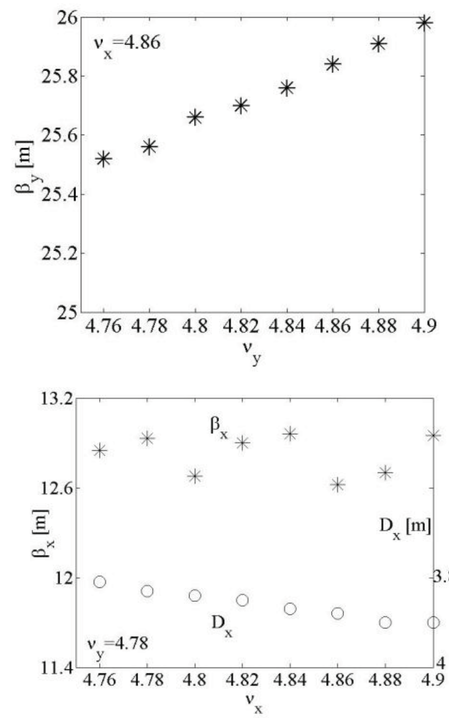

Figure 4: The comparison of the maxima of beta functions and dispersion functions for different working points near the tune (4.86, 4.78).

SIMULATION RESULTS

3-D simulations are performed for different working points with and without space charge effects by using the codes ORBIT [6].

Without space effects, there is no emittance growth and beam loss for all the working points.

At the early stage of acceleration, due to the low energy, space charge effects are serious. With the beam acceleration, the beam energy increase, and 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.

For the working point (4.86, 4.78), 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 working point (5.82, 4.80), there is serious beam loss. Up to 6% macro particles are lost during the 2000 turns tracking. The collimation efficiency is 91.4%, which means the uncontrolled beam loss is about 0.5%. Fig. 5 shows the 99% emittance evolution and beam loss during acceleration. There are three possible reasons which result in the serious beam loss for the working point (5.82, 4.80). The painted emittance is larger than (4.86, 4.78) in vertical direction; There is apparent emittance growth in horizontal direction, which may be induced by structure resonances, as shown in Fig. 1; the acceptance for the working point (5.82, 4.80) is smaller than (4.86, 4.78).

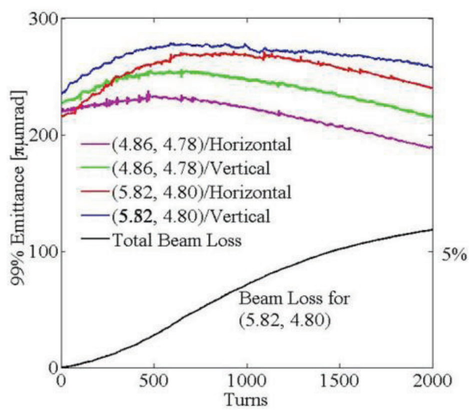

Figure 5: The 99% emittance evolution and beam loss during acceleration.

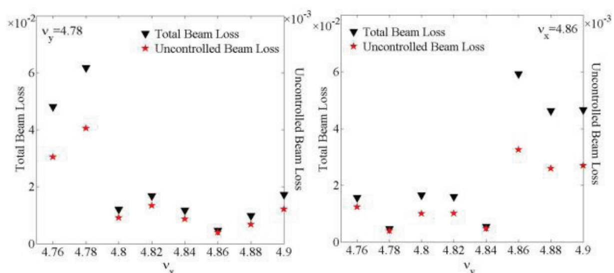

Figure 6: The beam loss during the 2000 turns tracking for working points near (4.86, 4.78).

The simulation results for working points near (4.86, 4.78) are shown in Fig. 6. There is serious beam loss for the working points (4.76, 4.78), (4.78, 4.78), (4.86, 4.86), (4.86, 4.88), which are near the coupling resonance. For the working points (4.9, 4.78), (4.86, 4.76), which are near the integer resonance or half integer resonance, much beam loss is also observed.

SUMMARY

In this paper, possible tune areas are explored and compared. Different working points near the tune (4.86, 4.78), which is prefered working point, are also examined and compared. Optical functions and acceptance for all the working points are calculated and compared. 3-D simulations are performed for different working points with and without space charge effects by using the code ORBIT. For the working point (5.82, 4.80), which is immune to the coupling resonance $2\upsilon_x$-$2\upsilon_y$=0, more serious beam loss than (4.86, 4.78) is observed in simulations. The beam loss may be induced by the structure resonances near the working point (5.82, 4.80). The simulation results for the working points near 4.86, 4.78) show that the prefered working point (4.86, 4.78) is the best working point in beam loss. There is serious beam loss for the working points (4.76, 4.78), (4.78, 4.78), (4.86, 4.86), (4.86, 4.88), which are near the coupling resonance. For the working points (4.9, 4.78), (4.86, 4.76), which are near the integer resonance or half integer resonance, much beam loss is also observed.

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