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BEAM DYNAMICS SIMULATION ABOUT THE DUAL HARMONIC SYSTEM BY PyORBIT

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Abstract

The space charge effect is a strong limitation in high-intensity accelerators, especially for low- and medium-energy proton synchrotrons. And for CSNS-II, the number of particles in the RCS is 3.9e13 ppp, which is five times of CSNS. To mitigate the effects of the strong space charge effect, CSNS-II/RCS (Rapid Cycling Synchrotron) will use a dual harmonic RF system to increase the bunching factor during the injection and the initial acceleration phase. For studying the beam dynamics involved in a dual harmonic RF system, PyORBIT is used as the major simulation code, which is developed at SNS to simulate beam dynamics in accumulation rings and synchrotrons. We modified parts of the code to make it applicable to the beam dynamic in RCS. This paper includes the major code modification of the Dual Harmonic RF system and some benchmark results. The preliminary simulation results of the dual-harmonic system in CSNS-II/RCS simulated by the particle tracking code PyORBIT will also be discussed.

INTRODUCTION

After reaching the designed beam power of 100 kW [1], The China Spallation Neutron Source (CSNS) has an update plan (CSNS-II) to increase the beam power to 500 kW (3.9e13 ppp), which means much stronger space charge effect will occur. To alleviate space charge effect, a dual harmonic RF system will be used for longitudinal painting to increase the bunching factor and the linac energy will be increased from 80 MeV to 300 MeV.

PyORBIT [2], which is developed at SNS, is used as the major simulation code to study the beam dynamic involved the space charge effect with and without the dual harmonic RF system in RCS (Rapid Cycling Synchrotron) of CSNS. To meet the requirement of simulation in acceleration process, some code modification is made. In order to verify whether the modified code is suitable for CSNS, a series of experiments are carried out to compare with the simulation results. Besides the modification made for acceleration process, some changes of the dual harmonic RF cavity model also need to be made to meet the needs of the changing voltage ratio between the second harmonic and the fundamental harmonic RF.

THE BENCHMARK OF LONGITUDINAL PARAMETERS

For checking the code as well as estimating the momentum acceptance of the CSNS/RCS, the longitudinal parameters with different momentum offsets are measured, which is shown in Table 1. BF and PF in Table 1 are the average value of bunching factor and momentum filling factor from 1200 to 1400 turn, which is about 2 ms to 2.4 ms, and the measured PF is gotten by tomography method [3]. More comparison of bunching factors can be found in reference [4], and the simulation results agree well with the measurements. From the measurement, we also found that the RCS transmission changed greatly with the longitudinal parameters. The RCS transmission under different longitudinal parameter combinations is shown as Fig. 1. The picture in lower right corner is the beam loss distribution under the bunching factor of 0.28 and the momentum filing factor of 0.86. The designed momentum acceptance of RCS is 1%, and the corresponding momentum filling factor is about 0.82 at 2 ms. The accuracy of designed momentum acceptance can be roughly judged according to the beam loss distribution in the figure, which also provides a reference for longitudinal painting optimization of CSNS-II.

Table 1: Comparison of Longitudinal Parameters Under Different Momentum Off-Set

Momentum off-set (%)	RCS transmission (%)	BF (measured)	BF (simulated)	PF (measured)	PF (simulated)
0.17	97.2	0.2503	0.2401	0.802	0.815
0.19	98.2	0.2606	0.2495	0.834	0.835
0.21	97.2	0.2704	0.2691	0.863	0.860

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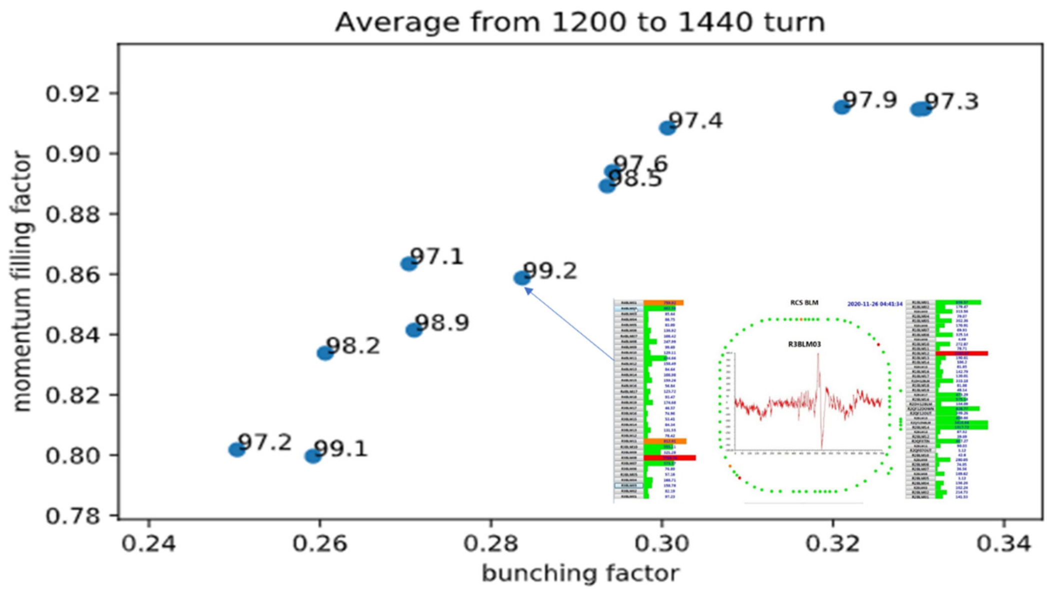

Figure 1: Comparison of RCS transmission under different longitudinal parameters. The beam loss distribution is measured by beam loss monitor, and the red bar near the arc section means large beam loss occur.

SIMULATION RESULTS WITH DUAL HARMONIC RF SYSTEM

The single-turn energy gain of dual harmonic RF system can be written as

$$dE = V_1 * \{sin\phi - r * sin[2(\phi - \phi_{1s}) + \phi_{2s}]\},$$

where V_1 is the amplitude of the fundamental rf voltage, r and ϕ_{2s} are the voltage ratio and the phase difference between the second harmonic and the fundamental harmonic RF, and ϕ_{1s} is the phase of the reference particle. Because the potential function of longitudinal Hamiltonian can decide the beam distribution [5], the comparison between them is made to verify the code as Fig. 2.

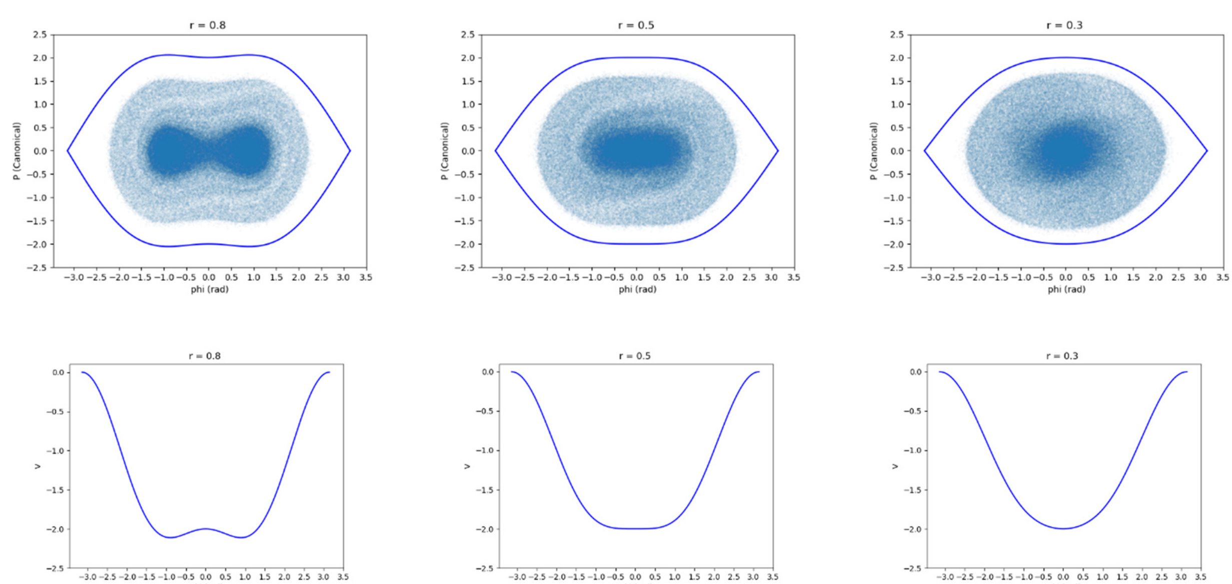

Figure 2: The longitudinal phase space and potential function with dual harmonic RF system while r equals 0.8, 0.5, 0.3 from left to right separately. The phase space density is proportional to the potential function value. The definition of coordinates can be found in reference[6].

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The accuracy of bunching factor is also important. Since the dual harmonic RF system is not installed at present, J-PARC's longitudinal parameter in the experiment of storage ring mode [7] is used to study the effect of different longitudinal painting on the bunching factor. As shown in Fig. 3, the simulation results of PyORBIT shows that a large voltage ratio with momentum offset can improve the bunching factor obviously, which comes to same conclusion as the reference, and the bunching factors of simulation are close to those of J-PARC experiment.

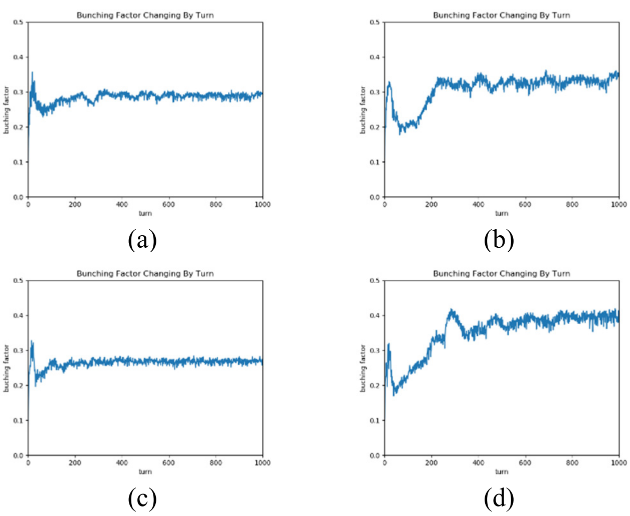

Figure 3: The simulation results of bunching factor by using PyORBIT with J-PARC's parameter at 181MeV [7]. The pictures above are respectively: (a) r = 0.5; (b) r = 0.5 and -0.2% momentum offset; (c) r = 0.8; (d) r = 0.8 and -0:2%. momentum offset.

For CSNS-II/RCS, different turns of acceleration period need to correspond to different voltage ratio and synchrotron phase. For this, a new cavity module has been added to the code, which can be simulated by a given voltage and energy change curve. The simulation results of beam distribution in phase space in 500 turn and 3000 turn are shown in Fig. 4, the variation of beam distribution with longitudinal parameters can be reflected.

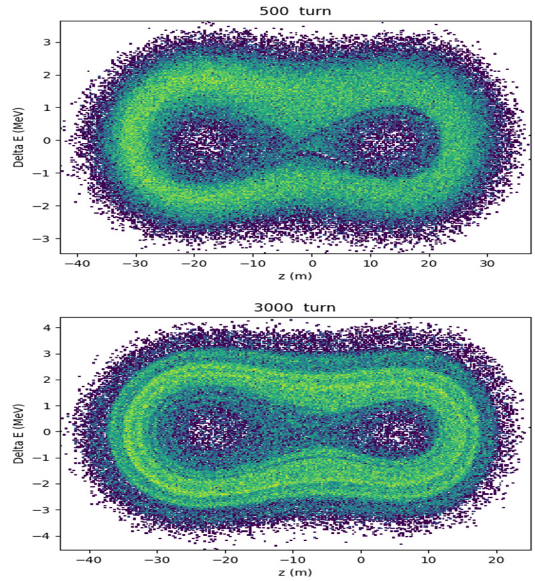

Figure 4: Longitudinal phase space of different turns at the same acceleration period.

CONCLUSION

By comparing with the experiment, the calculation of the longitudinal parameters is verified. The improved code can simulate the dynamics of double harmonic RF system in RCS, and the study of longitudinal painting in CSNS-II/RCS will be carried out on this basis.

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