SINGLE PARTICLE BEAM DYNAMICS DESIGN OF CSNS/RCS

S. Wang*, S. -X. Fang*, Q. Qin*, J.-Y. Tang*, J. Wei*+
Institute of High Energy Physics, Beijing,100049, China*
Brookhaven National Laboratory, USA+

Abstract

Rapid Cycling Synchrotron (RCS) is a key component of China Spallation Neutron Source (CSNS). It accumulates and accelerates protons to design energy of 1.6 GeV, and extracts high energy beam to the target. As a high beam density and high beam power machine, low beam loss is also a basic requirement. An optimal lattice design is essential for the cost and the future operation. The lattice design of CSNS is presented, and the related dynamics issues are discussed. The injection/extraction scheme and the beam collimation system design are introduced.

INTRODUCTION

China Spallation Neutron Source (CSNS) accelerator [1,2] consists of a low energy linac and a high energy Rapid Cycling Synchrotron (RCS). As a compromise among proton current, kinetic energy and the upgrade capability, CSNS linac output energy is chosen as 81 MeV in the first phase, and the extraction energy from the RCS is 1.6 GeV. The primary parameters of CSNS accelerator complex are shown in Table 1. At the repetition rate of 25 Hz, the accelerators can deliver beam power of 120 kW at phase I, and will be updated to 240 kW (phase II) or 500 kW (phaseII') by increasing the injection beam energy and intensity of RCS. The single particle beam dynamics design is presented in this paper.

Table 1: The primary parameters of CSNS

Project Phase	I	II	II'
Beam power (kW)	120	240	500
Repetition rate (Hz)	25	25	25
Average current (μA)	76	151	315
Beam energy on target(GeV)	1.6	1.6	1.6
LINAC energy (MeV)	81	134	230
Linac RF frequency (MHz)	324	324	324
Linac length (m)	41.5	67.6	77.6
Linac duty factor（%）	1.1	1.1	1.7
Accum. particles (10^{13})	1.88	3.76	7.8
Target	1	1	1 or 2

LATTICE DESIGN FOR RCS

Linear Lattice

The lattice design of the RCS should meet the basic requirements of the injection, accumulation, acceleration and extraction of beam, and can provide the beam a reasonable chromatic correction, closed orbit correction, coupling correction and beam collimation, and to promote the performance of beam.

The 3-fold or 4-fold symmetry lattice are investigated and compared in the RCS design. As a compromising of magnetic field quality and volume of the dipole, the length of the bending magnet is chosen as 2.1 m, and totally 24 dipoles are used for RCS. For accommodating momentum collimator, a gap with large dispersion function is required. In case of a four fold symmetry structure, there are 6 bending magnets at each arc, and with one or two missing dipole gap for momentum collimation, each arc shall be consisted by 3.5 or 4 90°phase advance FODO cells. To have large dispersion in missing dipole gap, the gap should be located in the middle of the arc, so a 4-fold symmetry lattice with 3.5 FODO cells at each arc is adopted [3]. Compare with 3-fold symmetry structure, 4-fold structure is also good for reducing the impact of the structure resonance, and the transverse collimation system can be accommodated in a separated straight section.

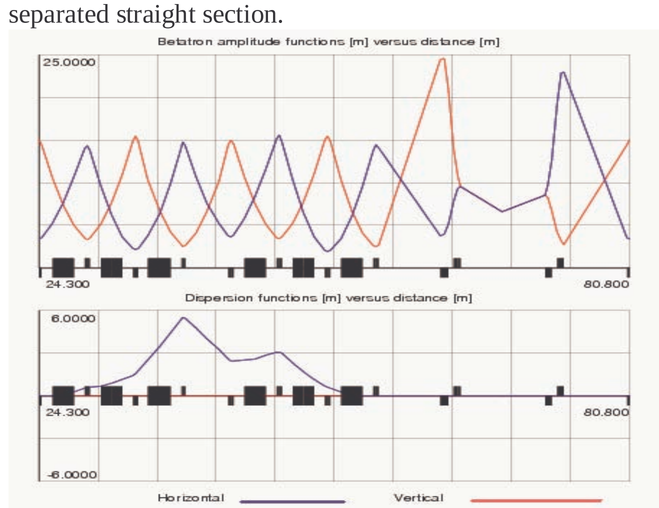

Figure 1: Twiss parameters for RCS lattice in one super-period.

Figure 1 gives the twiss parameters of one super-period. For there are 3.5 cells at each arc, the lattice function are anti-symmetric. It contains 24 dipoles and 48 quads. The circumference is 230.8 m. The base tunes are (5.82, 5.80). The straight section adopts doublet structure, and each straight section consists of two 6 m and one 9 m long drift space. The total dispersion free long straight section is 84 m. In the middle of the arc the missing dipole form a 4.1m straight section for momentum collimation. The peak dispersion is 5.4 m and the peak beta is < 25 m in the straight, and < 16 m in the arc. The

*E-mail: wangs@ihep.ac.cn

FODO arc should allow easy lattice correction. Table 2 indicates the primary parameters of the RCS lattice.

Table 2: The primary parameters of the RCS lattice

Injection energy (GeV)	0.081
Extraction energy (GeV)	1.6
Repetition rate (Hz)	25
Circumference (m)	230.8
Superperiod	4
Number of dipoles	24
Number of long drift	12
Total Length of long drift (m)	84
Betatron tunes (h/v)	5.82/5.80
Chromaticity (h/v)	-6.64/-7.27
Momentum compaction	0.041
Rev. periods (inj/ext, μs)	2.059/0.811

Figure 2 shows the geometry of the RCS. One of the four straight section is for transverse collimation, and the other three straight sections are for injection, extraction and RF station. One missing dipole gap in the middle of the arc is for the momentum collimation, and the other three can be left for dual harmonic cavities or other device in the future upgrade. To decrease the circumference of the RCS, the cell length in the arc is set to 10.2 m, and the effective length between quardrupole and dipole is only 0.6 m. These short straight sections are used for dipole correctors, trim quadrupole , sextupoles, beam position monitors (BPM) and vacumm bumps, and the space is very tight. There are 4 sextupoles, 8 quardrupoles, 8 dipole correctors, 8 BPMs and 4 vacuum bumps at each arc. To save space, all the BPMs are planed to be installed under the sextupoles and dipole correctors, and the vacuum bumps are planed to be installed under the dipole correctors.

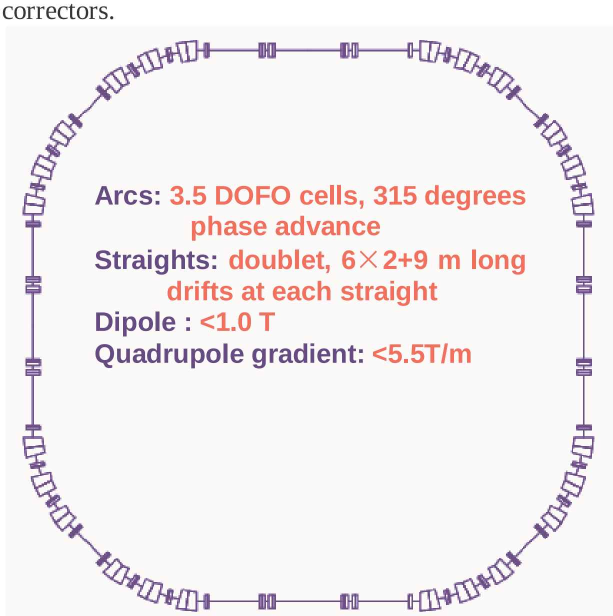

Figure 2: The geometry of RCS.

Chromaticity Correction

Although the nature chromaticity is not so large, as shown in table 2, to reduce the tune spread and correct the off-axis lattice functions, especially in the low energy part, 4 families sectupoles are used to correct the chromaticity to -0.5. The phase advance between two adjacent F sextupoles is nearly 90° , and the phase advance between two adjacent D sextupoles is also nearly 90° . The arrangement of the setupoles are interleaving. During one cycle of RCS, the importance of chromaticity correction is decreased with the energy increased, so the sextupoles are designed as DC magnets. Figure 3 and figure 4 respectively show the horizontal and vertical beta functions for Δp/p=0, ±1%, with and without chromaticity corrections. One can find that, without chromaticity correction, the deviation of vertical beta function is nearly 20%, after the proper chromaticity correction, these deviation becomes very small.

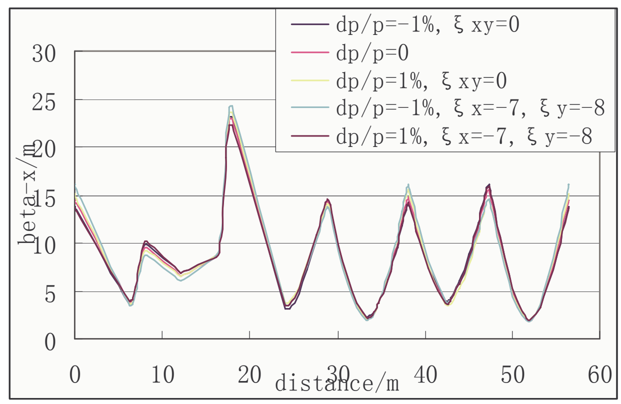

Figure 3: Horizontal on- and off-axis beta function for one super-period.

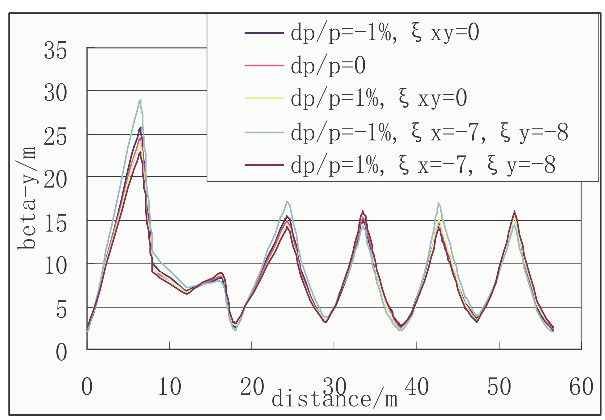

Figure 4: Vertical on- and off-axis beta function for one super-period.

The tracking was done for checking the dynamic aperture with only the nonlinear effect of the sextupoles. In two dimensional case (*x-y*), the tracking results show that the dynamic aperture for particles of Δp/p=±1% is large than $5\sigma_x \times 5\sigma_y$, where σ_x and σ_y are horizontal and vertical beam size.

Closed Orbit Correction and Trim Quadrupoles

There are 48 BPM in the whole RCS ring, each of them is installed just nearby a quadrupole. The number of dipole correctors in RCS is 40, in which 20 are for horizontal plane and 20 for vertical plane. The power supply for dipole corrector is programmable, and the dipole corrector should be ramped 10 to 20 steps during one RCS cycle. The maximum correction ability of dipole corrector is 1mrad at 1.6GeV. With these BPM and correctors, the closed orbit distortion can be well corrected.

For adjusting tune during ramping process, 32 trim quadrupoles are arranged in the RCS. The ISIS [4] has some experience on using the trim Quadrupoles, which are from the commissioning and normal operation. The operation mode of trim quadrupoles shall be further investigated.

BEAM LOSS AND COLLIMATION

In the whole design, beam losses should be controlled in a very low level. Based on the past operational experience, to allow hands-on maintenance for most accelerator components, an average uncontrolled beam loss should be not exceeding about one watt of beam power per tunnel meter. For CSNS case, in the first phase, one watt of beam power per tunnel meter corresponds to a fractional uncontrolled beam loss of 2×10^{-3}. To achieve this beam loss level, both longitudinal and transverse collimation systems are required to reduce the uncontrolled beam loss within the acceptable level for hands-on maintenance. By using the momentum collimators located at straight section in the middle arc and the transverse collimation located at long straight section, it is expected to obtain more than 90% collimation efficiency.

There is one momentum collimator located in the missing dipole gap of the arc. The type of the momentum collimator is direct absorber made of graphite and copper. The transverse collimation system adopts classical two-stage collimation. It consists of one primary collimator and five secondary collimators. The transverse collimation system takes a separate straight section, just downstream of the momentum collimators. Halo particles are scattered by the primary collimators, and the secondary collimator absorb these scattered particles.

INJECTION AND EXTRACTION

In order to reduce the tune depression and tune spread due to strong space charge effect, injection into the RCS is by using H^- painting method in both horizontal and vertical planes. Both correlated and anti-correlated painting schemes are available [5].

Figure 4 gives the injection scheme [6]. The whole injection chain is arranged in a 9 m long drift space, consists of four horizontal painting magnets (BH), four vertical painting magnets,(BV) and four fixed field bumping magnets (BC). The BC magnets are used to facilitate the design for the septum magnets and reduce the proton traversal in the stripping foil, and it will be switched off after the injection period, beside of an injection septum magnet, another septum magnet is used to direct the non-stripped or partially stripped H^- particles in the main stripping foil to a beam dump. A second stripping foil converts almost 100% the unusable particles states into protons. A very small fraction of H0 and H^- particles in high excited states are stripped by the magnetic field of BC3, and will form beam halo in the ring that will be finally stopped by the collimators. At the end of injection, the transverse emittance will be within 320 m.rad, and for uniform distribution, the designed space charge tune shift is 0.28.

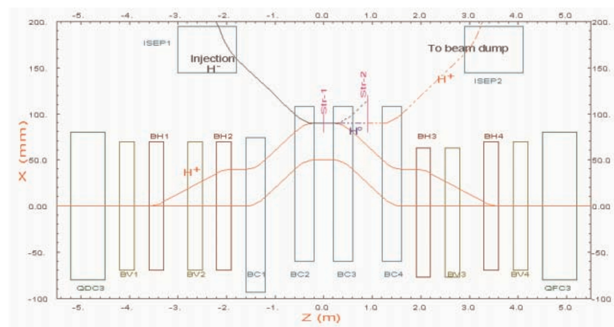

Figure 4: Injection scheme (BC1~BC4: closed-orbit bump magnets， BH1~BH： horiz. painting bumpers， BV1~BV4: vert. painting bumpers，QDC3 & QFC3: quads，ISEP1&2: septa).

The one-turn extraction from the RCS can be obtained by using a series of fast kickers followed by a Lambertson septum [7]. Pre-extraction orbit bumping is considered to reduce the strength requirement for the kickers and the beam loss in case of firing failure of one thyratron.

SUMMARY

An FODO cell and doublet hybrid structure lattice is presented for CSNS/RCS. It has a four-fold symmetry structure, and the lattice functions are anti-symmetry. The FODO cell arc ease to lattice correction and doublet straight section makes long uninterrupted straight for injection and extraction. The missing dipole gap in the middle of arc is suitable for momentum collimation. The lattice correction, beam collimation system and injection/extraction system of RCS all also introduced.

REFERENCES

[1] CSNS Conceptual Design Report (IHEP, China, 2005).
[2] J.Wei, S. Fu, S. Fang, these proceedings.
[3] J.Wei, S.Wang, et, al, these proceedings.
[4] C.M. Warsop, AIP Conf. Proc. 448 (1998) 104.
[5] J.Qiu, et al, these proceedings.
[6] J.Tang, et al; S.Wang et al, these proceedings.
[7] J.Tang, et al; S.Wang et al, these proceedings.