THE OPTIMIZATION OF BEAM DYNAMICS DESIGN FOR CSNS/RCS

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Abstract

The accelerator of China Spallation Neutron Source (CSNS) consists of a low energy linac and a Rapid Cycling Synchrotron (RCS)[1], in which RCS accumulates and accelerates proton beam, and delivers beam of 1.6 GeV to the neutron target. The optimization of beam dynamics design for RCS has been done. The optimizing design is introduced, and the details design and some simulation results are presented.

INTRODUCTION

China Spallation Neutron Source (CSNS) accelerator consists of a low energy linac and a high energy Rapid Cycling Synchrotron (RCS) [1]. 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 accelerator can deliver beam power of 100 kW at phase I, and is capable of upgrading to 200 kW (phase II) or 500 kW (phaseII') by increasing the injection beam energy, as well as the beam intensity of RCS. After the feasibility study report, the beam dynamics design was optimized, and the detailed design is presented in this paper.

Table 1: The primary parameters of CSNS

Project Phase	I	II	II'
Beam power (kW)	100	200	500
Repetition rate (Hz)	25	25	25
Average current (μA)	62.5	125	312.5
Beam energy on target(GeV)	1.6	1.6	1.6
LINAC energy (MeV)	81	134	250
Linac RF frequency (MHz)	324	324	324
Linac duty factor（%）	1.1	1.1	1.7
Accum. particles (10^{13})	1.56	3.12	7.8
Target	1	1	1 or 2

BEAM DYNAMIC 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 perform the necessary optics correction and beam collimation. Due to the requirement of the beam collimation for beam loss control in a high intensity proton synchrotron, the lattice with 4-fold structure is preferred for separated-function design: the collimation can be performed in a separate straight section. Also the lattice superperiod of 4 is better for reducing the impact of low-order structure resonance than superperiod of 3. RCS design chooses this kind of 4 super-period structure. The dedicated functions are accommodated in the different sections of ring, as shown in the sketch map in Figure 1.

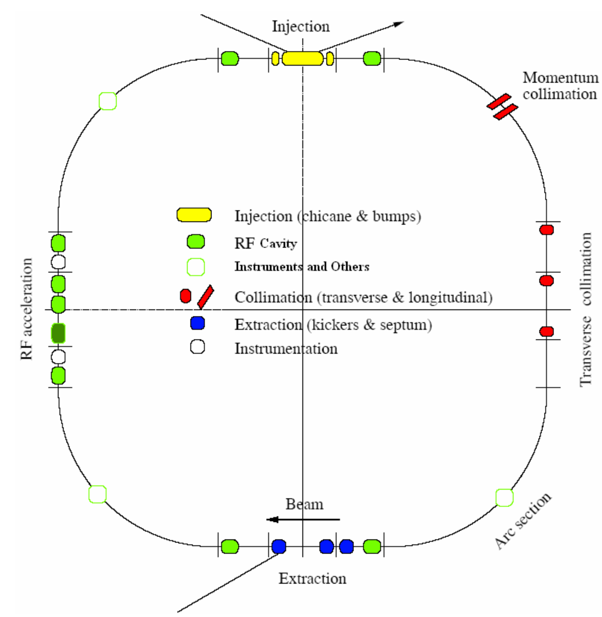

Figure 1: The sketch map of dedicated functions distributed in the different sections of ring

The optimization iteration for lattice design aiming at reducing the budget of RCS has been done. Decided by the characters of FODO cell, the gap of dipole is difficult to be further decreased, and also the aperture of quadrupoles at the position with large dispersion is also hard to decrease. To further decrease the gap of dipoles and the aperture of quadrupoles, and lower the budget of magnets and power supply, the new lattice scheme was proposed and adopted.

The optimized lattice is also the 4-fold structure based on triplet cell[1,2], and the whole ring consists of 16 triplet cells, with circumference of 227.92m. The number and length of dipole are the same as the previous lattice: totally 24 dipoles and 2.1m long for each. In each superperiod, the structure is mirror symmetry on the middle point of each super period. There are 6 dipoles at each arc, located at three triplet cells. In the middle of the arc, a 3m long space is reserved for accommodation of momentum collimators. Momentum collimators take only one of the four arcs, and the other three can be used for long beam instrumentation and other devices. In the two

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side cells in the arc, a 3.85m space is reserved between dipole and quadruples. In the each super period, an 11m long drift space is left in a triplet cell, and this uninterrupted long space is very good for accommodation of injection, extraction and transverse collimation system.

Figure 2 gives the twiss parameters of one super-period. The 48 quadrupoles are powered by 5 families power supply. The maximum beta function is less than 26m, and the maximum dispersion function is less than 4m. Especially in the middle of the arc, the dispersion is large and the horizontal beta function is small, and this is good for high efficiency momentum collimation. Take the advantage of the triplet, the double-waist beta function benefit not only the decreasing of the gap of dipoles and the aperture of RF cavities, but also the design of injection, extraction and beam collimation. Main parameters of optimized lattice are given in the table 2.

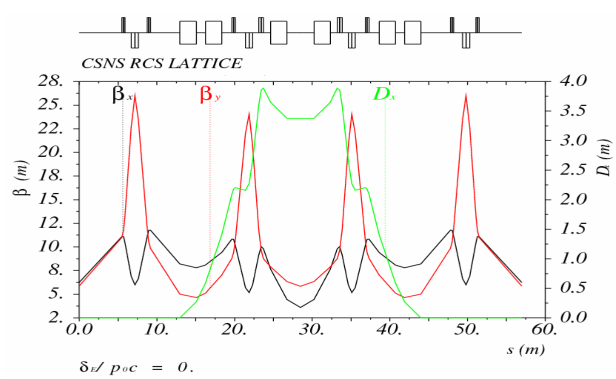

Figure 2: The twiss parameters of a superperiod

Table 2 Main parameters of optimized lattice :

Circumference (m)	227.92
Superperiod	4
Number of dipoles	24
Number of quadrupoles	48
Number of long drift	12
Total Length of long drift (m)	74.8
Betatron tunes (h/v)	4.82/4.80
Chromaticity (h/v)	-4.3/-9.2
Momentum compaction	0.041
RF frequency (MHz, h=2)	1.0241~2.3723
Max. RF voltage (kV)	165
Number of quad. power supply	5
Trans. acceptance (µm.rad)	540

Lattice Correction

Three kinds of correction are considered: chromaticity correction, closed orbit correction and tune correction.

Although the nature chromaticity is not so large, as shown in Table 2, and it operates under the transition energy, the chromaticity correction is not indispensable. According to the commissioning experience of SNS accelerator, to meet the requirement of commissioning and machine study, the chromaticity correction is designed. Totally 16 sextupoles are used, and powered with 2 families power supply. The power supply is DC, so the chromaticity can be corrected only at the low energy stage. The triplet based lattice is not good for chromaticity correction design, and with two families power supply, only first order chromaticity can be corrected. The tracking was done for checking the dynamic aperture with the nonlinear effect. In two dimensional case (x-y), the tracking results show that the dynamic aperture with sextupoles only for particles of $\Delta p/p=\pm1\%$ is around $4.5\sigma_x\times2.5\sigma_y$, where σ_x and σ_y are horizontal and vertical beam size. With sextupoles and high order field of dipoles and quadrupoles, the dynamic aperture is decreased to $2.5\sigma_x\times2\sigma_y$.

There are 32 BPM in the whole ring for closed orbit correction, two BPM in each triplet cell. The number of dipole correctors in RCS is 34, in which 17 are for horizontal plane and 17 for vertical plane. The power supply for dipole corrector is programmable, and the dipole corrector should be ramped from 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.

Due to the resonant working mode of main dipoles and quadruples, the saturation will occur in high energy stage in an RCS cycle. The saturation will induce the mismatch between dipoles and quadrupoles, and make the deviation of twiss parameters and tunes. When the deviation is large, the correction is necessary. To perform this kind of correction, the trim quadrupoles are adopted in the optics design. Totally 24 trim quadupole are powered with programmable power supply. They can also be used to correct or compensate some of the space charge effect, and also benefits to the response matrix beam measurement.

Space Charge Effects and Emittance Growth

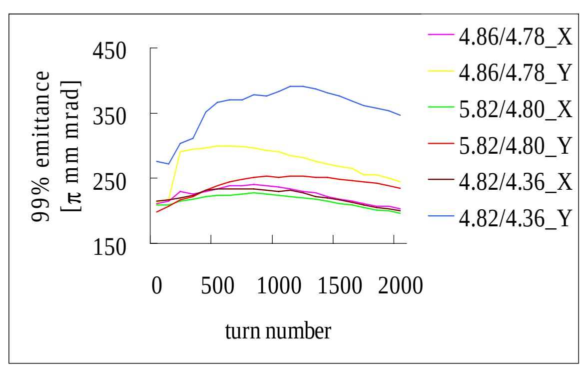

Figure 3: The emittance growth vs. transverse tune

In RCS with high beam power, especially in the low energy part, the beam is space charge dominated, and the space charge effects are the main source of beam loss. The space charge effects limit the maximum beam density, as well as beam power. Many simulation works were done for the study of space charge effects by using codes ORBIT and SIMPSONS. Various conditions, which may influence the space charge effects and beam loss, are considered. Some injection painting optimizations were made for decreasing halo formation and tune spread. The beam loss and emittance growth are compared for different conditions. Figure 3 shows the emittance growth vs. transverse tune, in which tune of ν_x/ν_y=5.82/4.80 is best for the emittance growth control. The simulation results are the foundation of physics design and the choice of design parameters.

Beam Collimation System

To control the beam loss, both longitudinal and transverse collimation systems are considered. The transverse collimation system adopts the two-stage collimation system. It consists of one primary collimator and four secondary collimators. The transverse collimation system takes a separate straight section, just downstream of the injection area. Halo particles are scattered by the primary collimator, and absorbed by the secondary collimators. It is expected to have a collimation efficiency of over 90% for the collimation system.

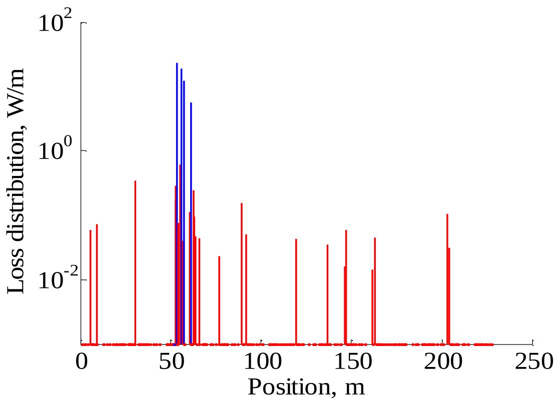

Figure 4: Beam loss distribution in the RCS with transverse beam collimation

The painting beam emittance is around 320πmm.mrad, and the primary collimator is movable, the acceptance can be changed. The design of secondary collimators is now changed from fixed aperture type to movable type with air cooling, similar to that of J-PARC[3]. The space for momentum collimator is reserved in the middle of the arc, however, according to the simulation study and operation experience of J-PARC and SNS, momentum collimator will not be installed in the phase of 100kW beam power. Figure 4 shows the simulated beam loss distribution by ORBIT, in which acceptance of primary collimator is 350πmm.mrad, secondary collimator is set to 420πmm.mrad, and the acceptance in the other part of the ring is 540πmm.mrad.

INJECTION AND EXTRACTION

In order to depress strong space charge effect, injection into the RCS is performed by using H- stripping and painting method to match the small emittance beam from linac to large emittance beam in RCS. Figure 5 shows the injection scheme. The whole injection chain is arranged in a 11 m long free straight section, consisting of four horizontal painting magnets (BH), four vertical painting magnets (BV) , and four fixed orbit bump magnets (BC). To avoid using ceramic chamber with a complicated shape in the injection region, the BC magnets will work in DC mode. In general, DC mode will increase the traversal number in the stripping foil, but this problem can be solved by adding an additional offset in the horizontal painting orbit. When the injection is finished, the offset is decreased to 0 quickly, and the additional traversal is avoided.

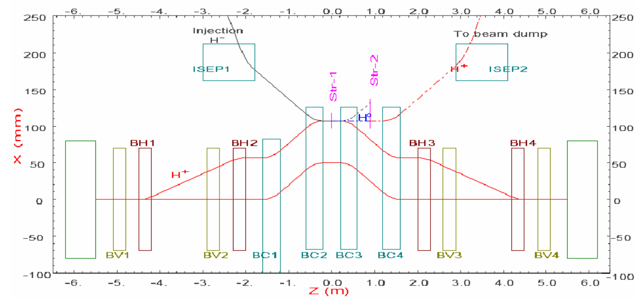

Figure 5 Injection component layout.

The 1.6GeV proton beam is extracted by one-turn extraction from RCS. The bunch length is about 70~100ns, and the space between two bunches is about 330~360ns. The beam is vertically kicked by a series of kicker to a horizontal bending Lambertson type septum. The rise time of kicker is required to be less than 250ns and peak field need to be kept more than 550ns for high efficiency extraction. The vertically kicked orbit should have a separation large enough to put the septa between the acceptance of circulating beam and extracting beam. The auxiliary bump magnets are adopted to provide additional extraction orbit and ease the kicker requirement. The extraction system is inserted in one 11 m long straight section. The layout of components is shown in Figure 6. There are 7 kickers, one is put to the position before a defocusing quadrupole in a triplet cell, the other 6 kickers, together with Lambertson and auxiliary bump magnet, are put in the 11 m long straight section. The space between the seventh kicker and auxiliary bump magnet is reserved for installing additional three kickers in case of necessary.

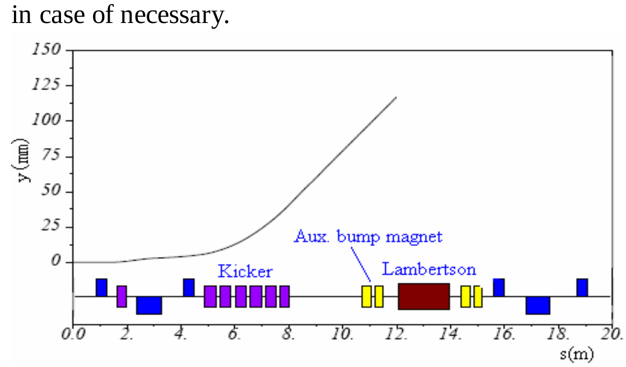

Figure 6: The layout of Extraction components

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[3] KEK Report2002-13, Mar. 2003