STUDY OF MAGNETS SORTING OF THE CSNS/RCS DIPOLES AND QUADRUPOLES*

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Abstract

The Rapid Cycling Synchrotron plays an important role in the China Spallation Neutron Source. RCS accumulates and accelerates the proton beams from 80MeV to 1.6GeV for striking the target with the repetition rate of 25Hz. RCS demands low uncontrolled loss for hands on maintenance, and one needs a tight tolerance on magnet field accuracy. Magnet sorting can be done to minimize linear effects of beam dynamics. Using closed-orbit distortion (COD) and beta-beating independently as the merit function, and considering maintaining the symmetry of the lattice, a code based on traversal algorithm is developed to get the dipoles and quadrupoles sorting for CSNS/RCS. The comparison of beam distribution, collimation efficiency and beam loss are also investigated according to beam injection and beam accelerating.

INTRODUCTION

The CSNS accelerator consists of a low energy H^- Linac and high energy RCS. H^- beam with energy of 80MeV is scraped and transformed into proton beam by the carbon foil located in the injection region. After around two hundred turn accumulation, the proton beam is accelerated to 1.6GeV and then extracted to strike the target with the design power of 100KW. For the convenience of maintenance and high power requirements, the uncontrolled beam loss should be less than 1 Watt/m. In order to achieve this goal, the expected magnet errors are designed to be in the order of 10^{-3} for main dipoles and quadrupoles. Table 1 shows the main parameters of RCS [1].

Table 1: Main Parameters of RCS

Parameters	Units	Values
Circumference	m	227.92
Repetition Rate	Hz	25
Average current	μA	62.5
Inj. Energy	MeV	80
Ext. Energy	GeV	1.6
Beam Power	kW	100
Quad		48
Dipole		24
Corrector		16/16
BPM		32/32
Nominal Tunes(H/V)	1	4.86/4.78

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As a key component of CSNS, RCS consists of 4-fold symmetric structure, and each of which is constructed by a triplet cell. Figure 1 shows the twiss parameters of RCS [2]. The long drift is reversed for the installation of cavities, collimator, injection elements and extraction elements, and the dispersion function in this area is designed to be zero. The short drift in the arc of the accelerator is reserved for installation of BPMs, correctors, sextupoles, and so on.

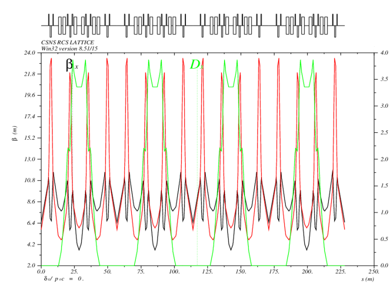

Figure 1: Twiss parameters of CSNS/RCS.

In section 2 we present in detail the sorting strategies. In section 3 we apply them to the CSNS/RCS model. In section 4 we investigate the sorting effects according to beam injection and beam accumulation. Conclusion is drawn in section 5.

SORTING STRATEGIES

Algorithm Description

Supposing there is M magnets should be arranged in M locations, the problems seems to be settled to find the solution of permutation of the M magnets. Now the steps of solving the problem are described as follows:

i) If there are two magnets, and the magnets indexes are A and B, the solution can be descripted as the order $\{A, B\}$ or $\{B, A\}$;

ii) If there are three magnets, and the magnets indexes are A, B and C. Firstly, the C magnet is fixed in the third location, and then the other two magnets can be sorted

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according to step one. Secondly, the C magnet is fixed in the second location, and then the other two magnets can also be sorted according to step one. Lastly, the C magnet is fixed in the first location, and then the other two magnets can also be sorted according to step one.

iii) If there are four magnets, and the magnets indexes are A, B, C and D. Firstly, the D magnet is fixed in the fourth location, and the other three magnets can be sorted according to step two. Secondly, the D magnet is fixed in the third location, and the other three magnets can also be sorted according to step two. Thirdly, the D magnet is fixed in the second location, and the other three magnets can also be sorted according to step two. Lastly, the D magnet is fixed in the first location, and the other three magnets can also be sorted according to step two.

iv) If there are M magnets, the magnet sorting can be done by repeating the above steps.

The above algorithm was developed with MATLAB, and then embedded in Accelerator Toolbox [3]. The above algorithm has advantage for its high efficiency on seeking the solutions and especially for a high memory tolerance compared with the code integrated in MATLAB such as *perms*.

Dipole and Quadrupole Sorting Strategies

There are 24 dipoles located along the azimuth of the ring, and can be divided into type-A and type-B dipoles. Type-A and type-B dipoles are powered by one power supply system but with different water cooling system. As shown in figure 2, the yellow column depicts type-A dipoles while the green column depicts type-B dipoles. In order to get a good arrangement of the dipoles, one needs to compare the closed orbit distortion (COD) caused by dipoles field errors and pick up the smallest closed orbit distortion. The process of the dipole sorting was to be done in two steps. Firstly, type-B dipoles were arranged for its corresponding smallest COD. And then, after the order of type-B dipoles were fixed, and the arrangement for type-A dipoles was figured for the evaluation of the COD. The dipoles field measurement was done in DC mode and AC mode, however, the DC dipoles field error was not conformed to AC dipoles field error very closely, and the most important that, the repeatability of field measurement in DC mode is about 2E-4 while that in AC mode is about 5E-4. So the arrangement of the dipoles was determined by DC field measurement.

There are 48 quadrupoles located along the ring, and powered by 5 group power supplies as follows: two strings of eight Q206 (diameter 206mm) quadrupoles, one string of sixteen Q272 (diameter 272mm) quadrupoles, one string of eight Q222 (diameter 222mm) quadrupoles, and one string of eight Q253 (diameter 253mm) quadrupoles. The quadruple distribution along the CSNS/RCS ring is also shown in figure 2. The red column depicts quadrupole Q206 with two power supplies, the blue column depicts quadrupole Q272, the pink column depicts quadrupole Q222, and the cyan column depicts quadrupole Q253.

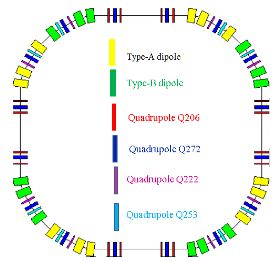

Figure 2: Magnet distribution along the CSNS/RCS ring.

DIPOLES AND QUADRUPOLES SORTING RESULTS

The field errors of dipoles can cause large closed orbit distortion, and that will make the central of beam oscillate close to the vacuum chamber. On the one hand, scattering along the vacuum chamber can make beam loss. On the other hand, the quantity of the magnet field off the center is a little worse than that in the centre of the magnet. So the dipoles should be sorted carefully. Firstly, one of the type-B dipoles was installed in the tunnel. Secondly, the left eleven type-B dipoles were carefully sorted by founding the smallest closed orbit distortion. Lastly, after the positions of the type-B dipoles fixed, the left twelve type-A dipoles were carefully sorted again by founding the smallest closed orbit distortion.

The field errors of the quadrupoles can cause beta beating, destroy symmetry of the lattice structure, and make beam emmittance growth. On the one hand, the lattice symmetry should be well restored. On the other hand, beta beating caused by quadrupoles should be well compensated by quadrupoles itself. When doing the sorting of the quadrupoles Q272, the sixteen magnet are divided into two groups according to their absolute non-uniformity field errors, and one group with larger non-uniformity field errors while the other group with smaller non-uniformity field errors. Firstly, the eight quadrupoes in the larger non-uniformity field errors group are carefully arranged. One thousand of the quadrupoles sorting patterns with small beta beating are saved, and then according to the symmetry of lattice structure, a reasonable sorting pattern is adopted. Secondly, the left eight quadrupole Q272 are carefully sorted, not considering the lattice symmetry. After the quadrupole Q272 arrangement is fixed, the quadrupole Q222, quadrupole Q206, and Q253 are carefully sorted. Figure 3 in left shows the closed orbit distortion comparison after 24 dipoles sorting. The red line indicates the closed orbit distortion caused by random arrangement of the dipoles, and the dark line indicates the closed orbit distortion caused by carefully sorting arrangement of the dipoles, and the closed orbit distortion decreased from 8mm to 1.5mm. Figure 3 in middle and right show the comparison of the horizontal beta beating from quadrupoles sorting, and the red line depicts the beta beating with random quadrupole arrangement while the dark line depicts the beta beating with sorting quadrupole arrangement.

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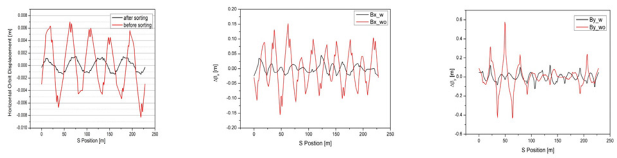

Figure 3: Left: The comparison of the horizontal closed orbit distortion after dipoles sorting. Mid: the comparison of the horizontal beta beating after quadrupoles sorting. Right: the comparison of the vertical beta beating after quadrupoles sorting.

THE EFFECTS OF MAGNETS SORTING TO BEAM DYNAMICS

Beam Distribution

In the present numerical simulation, 2e5 macro particles were used. Figure 4 shows the comparison of beam distribution after dipoles and quadrupoles sorting. Because of the strong space charge effects, the effects of sorting magnet are not very obvious. And that can also be proved in Figure 5, which shows the comparison of the emittance at the end of anti-correlated injection.

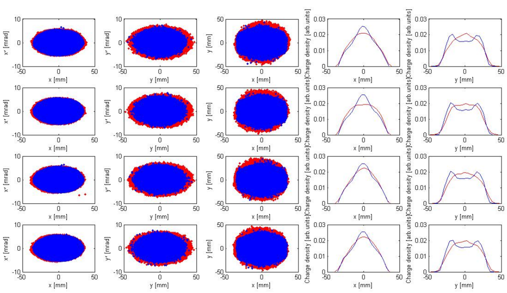

Figure 4: Beam distribution after the dipoles and quadrupoles sorting. From the top to bottom, the distribution corresponds to random dipoles, sorting dipole, random quadrupoles and sorting quadrupoles respectively.

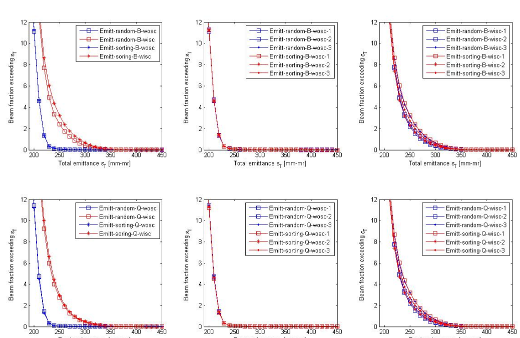

Figure 5: The emittance comparison of due to different cases.

Collimation Efficiency and Beam Loss

The collimator efficiency is defined as the ratio of particles lost in collimator than that lost in the ring. Figure 6 shows the comparison of collimator efficiency and beam lose after magnet sorting. From left to right, the first two groups correspond to dipole errors neglecting space charge effects in beam injection and accelerating respectively. The second two groups correspond to dipole errors considering space charge effects in beam injection and accelerating respectively. The third two groups correspond to quadrupoles errors neglecting space charge effects in beam injection and accelerating respectively. The fourth two groups correspond to quadrupoles errors considering space charge effects in beam injection and accelerating respectively.

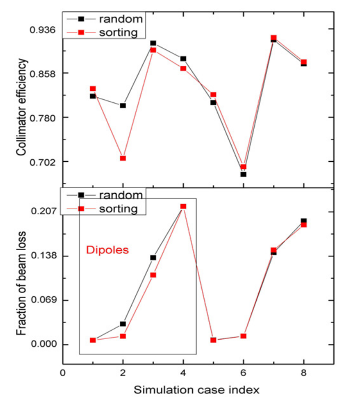

Figure 6: The comparison of collimation efficiency and beam loss.

CONCLUSIONS

For the requirements of the high power, the main dipoles and quadrupoles of CSNS/RCS should be carefully arranged along the azimuth of the accelerator. A code based on traverse algorithm is well developed to get all permutation results of sorting and to pick the best result according to lattice symmetry, small beta beating and small closed orbit distortion. After dipoles and quadrupoles sorting, the beta beating and closed orbit distortion are decreased, and the lattice symmetry are restored. The effects of magnet sorting are carefully investigated according to beam distribution, collimator efficiency and beam loss. Due to strong space charge effects, magnets sorting effects to beam dynamics are not very obvious in our simulation.

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