MAGNET SORTING OF THE CSNS/RCS DIPOLES AND QUADRUPOLES *

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Abstract

As a key component of the China Spallation Neutron Source (CSNS) Project, the Rapid Cycling Synchrotron (RCS) accumulates and accelerates the proton beams from 80MeV to 1.6GeV for extracting and striking the target with a 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.

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 four hundred turn accumulation, the proton beam is accelerated to 1.6GeV and then extracted to strike the target with the design power of 100 kW. 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 lower 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

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.
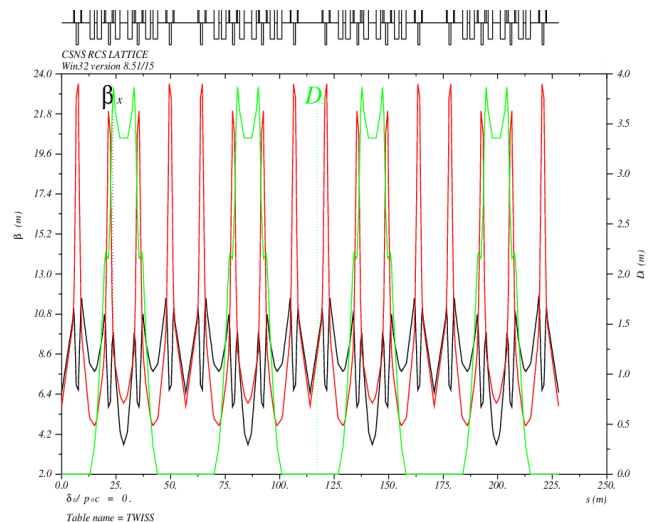

Figure 1: Twiss parameters of CSNS/RCS.

SORTING STRATEGIES

Algorithm Description

A simple script is developed to calculate the permutations of a given vector, and then embedded in our code based on Accelerator Toolbox [3]. By setting the closed orbit distortion or beta-beating as the merit function, the best sorting result can be picked from a lot of reasonable results according to the symmetry structure of the Lattice. However, it seems difficult and time consuming to get the sorting results when all of the dipoles errors and quadrupole errors calculated simultaneously, so we get it step by step.

Dipole Sorting Strategies

There are 24 dipoles located along the azimuth of the ring, and can be divided into type-A and type-B dipoles, a. 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 type-B dipoles were given, 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.
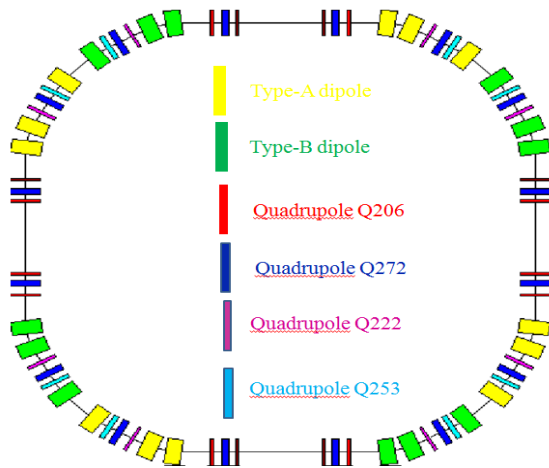

Figure 2: Magnet distribution along the CSNS/RCS ring.

Quadrupole Sorting Strategies

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. So far, the field measurements of one strings of eight Q206, one string of sixteen Q272 and one string of eight Q222 finished. Table 2 shows the RMS values of the quadrupoles discretization field errors from the quadrupole field measurements in DC mode.

Table 2: RMS Values of the Quadrupoles Discretization Field Errors from Field Measurement in DC Mode

Quadrupoles	RMS Values
one string of eight Q206	5.62E-4
one string of sixteen Q272	7.95E-4
one string of eight Q222	3.03E-4

For an early installation in tunnel, the sorting results should be followed by the results of the field measurement. The quadrupole field measurement is a three step process as follow: one string of sixteen Q272, one string of eight Q222 and one string of eight Q206.The field measurements of the quadrupoles are also carefully taken both in DC mode and in AC mode. However, as descripted in dipole sorting section, the repeatability of the field measurement in AC mode is much worse than that in DC mode, so we just used the field measurement data in DC mode. The process of sorting is simultaneous with the filed measurement, so the quadrupole Q272 should be figured out firstly, quadrupole Q222 is followed and quadrupole Q206 is at last. Sorting of the quadrupoles is a little different than the dipoles sorting. When sorting quadrupole Q272, it is important to choose a result with good lattice symmetry, so the arrangement of quadrupole Q272 didn't mean a smallest beta beating. But in the sorting process of quadrupole Q222 and quadrupole Q206, we picked up the smallest beta beating that is because the non-uniformity of quadrupole Q272 is larger than that of quadrupole Q222 and quadrupole Q206.

DIPOLES 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 one hand, scattering along the vacuum chamber can make beam loss. On the other hand, the quantity of the magnet field 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. Figure 3 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.
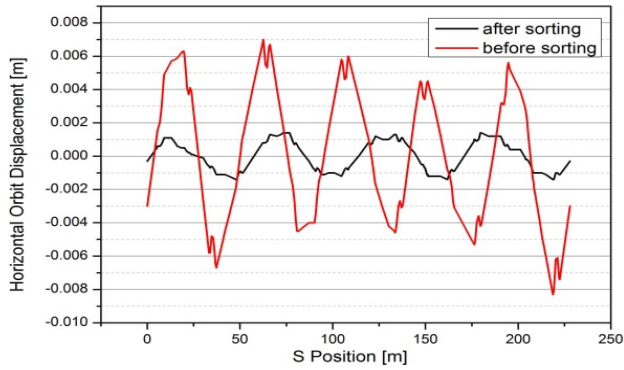
Figure 3: The comparison of the horizontal closed orbit distortion from dipoles sorting.

QUADRUPOLES SORTING RESULTS

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 and quadrupole Q206 are carefully sorted. Figure 4 shows 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.
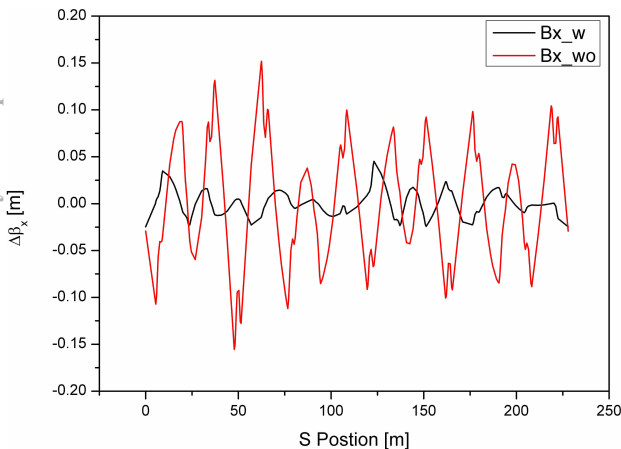

Figure 4: The comparison of the horizontal beta beating from quadrupoles sorting.

Figure 5 shows the comparison of the vertical beta beating from magnet sorting; the red line depicts the random arrangement while the dark line depicts the sorting arrangement respectively.
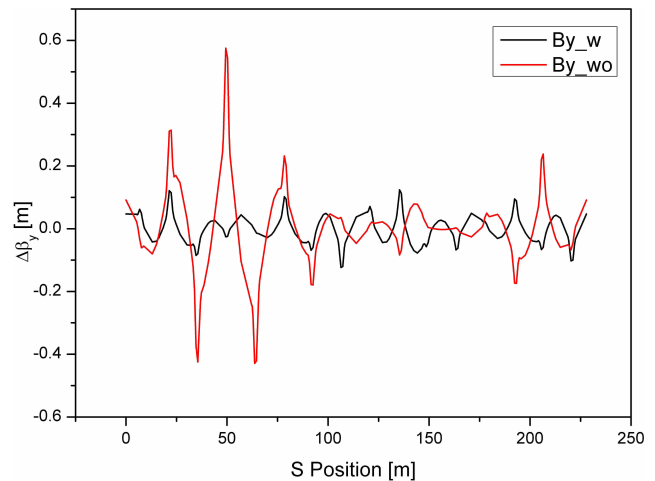

Figure 5: The comparison of the vertical beta beating from quadrupoles sorting.

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.

REFERENCES

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[3] URL http://www.slac.stanford.edu/~terebilo/at/