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# STUDY ON MAGNET SORTING OF THE CSNS/RCS DIPOLES

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*Abstract*

The 1.6 GeV Rapid Cycling Synchrotron (RCS) of the China Spallation Neutron Source (CSNS) is a high-power pulsed proton machine aiming for a 500 kW output beam power. Now, the routine output beam power has been increased to 100 kW. However, the horizontal bare orbit in the ring is large and the number of correctors is small, which brings great challenges to the ramp-up of beam power. It is found that the bare orbit in AC mode is 3 to 4 mm larger than that in DC mode. The reason is that the AC dipoles field error is larger than DC dipoles field error. Therefore, it is proposed to sort dipoles again according to the AC dipoles field error. In order to reduce the risk of beam commissioning, fewer magnets should to be moved to achieve smaller orbit. The best results of moving 2 to 6 magnets were calculated. After sorting, the orbit can be reduced by 3 to 4 mm, which reduces the difficulty of orbit correction.

## INTRODUCTION

CSNS is a high-power pulsed spallation neutron source, which consists of an accelerator, a target station and several spectrometers [1]. The CSNS accelerator is composed of a negative hydrogen linear accelerator with energy of 80 MeV in CSNS-I and 300 MeV in CSNS-II, a 1.6 GeV RCS and transportation lines. The negative hydrogen ions are stripped into protons at the injection point and accelerated to 1.6 GeV with about 20,000 turns in the ring and finally are led out to strike the target to produce neutrons. The design beam power is 100 kW in CSNS-I and 500 kW in CSNS-II. The RCS beam commissioning started in May 2017 and the neutron beam was successfully obtained on August, 2017. CSNS made available for the user program in August, 2018. At present, the pre-research work of CSNS-II is also in progress. In order to achieve the goal of beam power with 500 kW, it is planned to use a radio frequency ion source to increase the peak current from 15 mA to 50 mA, some superconducting cavities were proposed to increase the linear energy to 300 MeV. In the RCS ring, the injection area will be modified and 3 magnetic alloy cavities will be added to reduce the influence of space charge effect on the beam.

The most important issues for high intensity proton accelerator are controlling and minimizing beam loss to keep machine activations within a permissible level (<1 W/m). However, the beam emittance and the horizontal orbit in the RCS ring is a little large, which leads to relatively large radiation dose in some places and increases the difficulty of maintenance. This paper mainly discusses the reasons and solutions of the larger beam orbit. There may be several reasons for the large horizontal orbit of the ring. Firstly, the large AC dipoles field error leads to the large bare orbit. Secondly, the number of correctors and beam position monitors (BPM) is small, which is not conducive to orbit measurement and correction. And there is not enough space in the ring to install new correctors and BPMs. Thirdly, the RCS lattice adopts triplet structure, which is unfavourable for orbit correction in a certain direction compared with FODO structure. Finally, BPM offsets cannot be accurately measured for group controlled quadrupole magnets, which increases the difficulty of orbit correction. Since the last three items are not easy to change, this paper will analyse and proposes a possible scheme for magnet sorting of the dipole magnets from the first aspect.

## ORBIT DIFFERENCE

### *Introduction to CSNS/RCS*

The RCS/CSNS is 227.92 m and triplet is used as the basic unit of lattice design. The lattice is a 4-fold symmetrical structure with four triplet elements in each arc region. Figure 1 shows the twiss parameters of RCS. There are 24 dipole magnets in the whole ring are powered by one power supply and 48 quadrupole magnets are powered by 5 power supplies. In order to measure and correct the beam orbit, 32 bi-directional BPMs and 34 correctors are installed in RCS Ring.

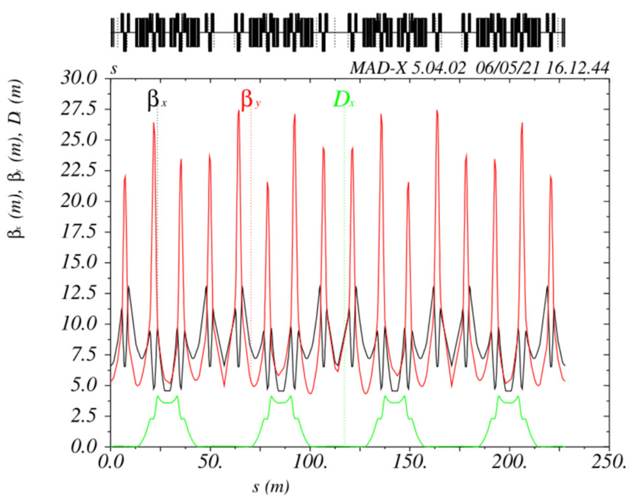


Figure 1: Twiss parameters of CSNS/RCS.

### *Orbit Difference Between AC and DC Mode*

CSNS normally operates in AC mode, but it will switch to DC mode for parameter measurement and correction in the initial stage of physical beam commissioning and machine study, which provides some reference for parameter selection for AC mode. In DC mode, the beam orbit can be corrected to 3 mm in horizontal plane and 2 mm in vertical plane. In AC mode, the vertical orbit can still be corrected to less than 2 mm, however the horizontal orbit can only be corrected to 5-6 mm [2]. Therefore, the horizontal orbit after correction is still large, which brings great challenges to

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the ramp-up of beam power. It is also found that the vertical bare orbit of AC mode at the injection time is basically the same as that of DC mode in the range and shape, while the horizontal bare orbit of AC mode is 3-4 mm larger than that of DC mode, as shown in Fig. 2.

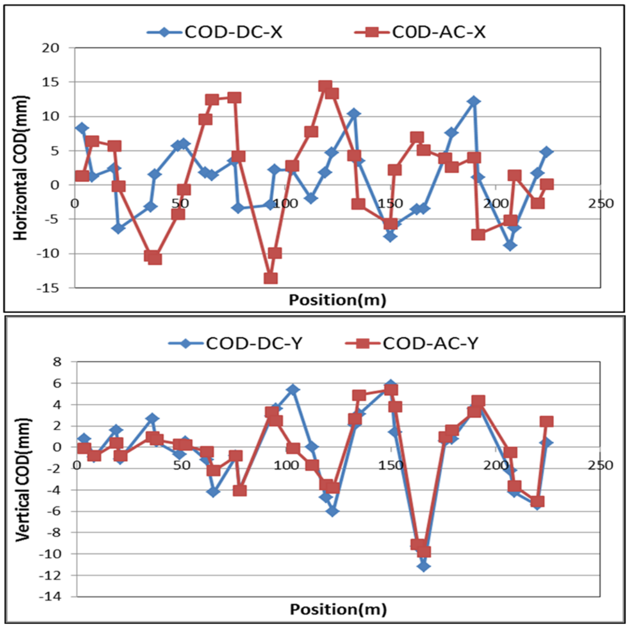


Figure 2: Bare orbits for DC mode and AC mode.

### *Dipole Field Error and Closed Orbit Distortion*

The beam bare orbit is mainly caused by magnet error and alignment error, while the alignment error is the same in DC mode and AC mode, so it is speculated that the difference may be caused by different dipole field error. Figure 3 shows the difference of dipole field error between AC mode and DC mode. It shows that the AC dipole error is significantly greater than the DC dipole error. The first dipole is a prototype and its AC dipole error is more than 0.2%, which will have a great impact on the beam orbit.

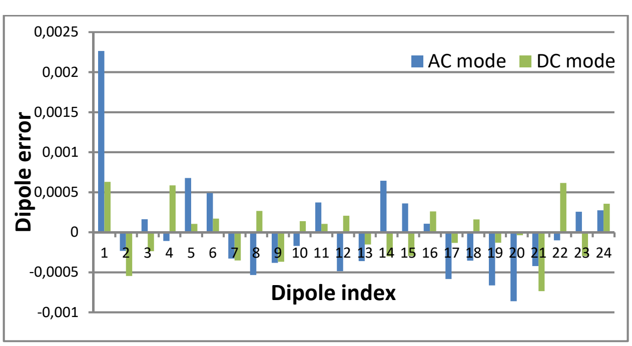


Figure 3: The DC and AC dipoles field error.

The closed orbit distortion caused by dipole field error are calculated by MADX [3] program and the results are shown in Fig. 4. In DC mode, the closed orbit is about 1.75 mm, while the closed orbit is about 5-6 mm in AC mode. The difference between two mode is about 3-4 mm, which is close to the difference of actual orbit now. From the calculation results, we speculate that large AC dipole field error is an important reason for the large horizontal orbit in AC mode.

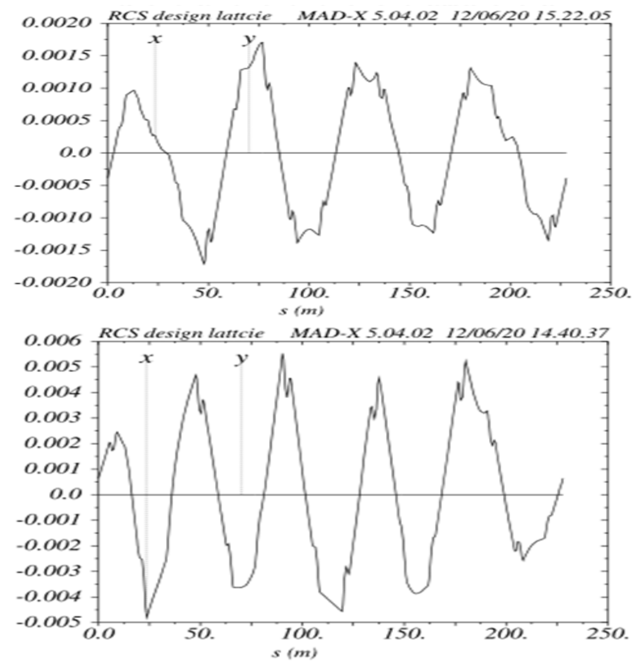


Figure 4: Horizontal closed orbit distortion from dipole field errors (The top is DC mode, the below is AC mode).

## MAGNET SORTING OF DIPOLES

As mentioned above, the magnetic field error is different between DC mode and AC mode, resulting in different closed orbit distortion. In order to reduce bare orbit in AC mode and realize orbit correction more easily, the magnet sorting of dipoles is proposed again. In 2014, magnets were sorted before entering tunnel, and the calculation was based on DC dipole field error data [4]. The magnets are divided into type-A (12) and type-B (12) due to the different direction of water-cooling wiring. At that time, the strategy was to arrange type-B first and then type-A. For type-B, one magnet is fixed first, and the remaining 11 magnets are fully arranged to compare the closed orbit distortion and pick up one scheme with the smallest closed orbit. After type-B is determined, type-A adopts the same operation. Since there are 24 dipoles in total, the whole algorithm takes more than one week with an ordinary computer.

In order to reduce the risk of beam commissioning and time cost, it is necessary to change fewer magnets to achieve smaller orbit for magnet sorting again. We consider 2 to 6 magnets moving schemes. The program is based on Open XAL accelerator physics software platform, which is developed in Java language and adopted by many

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laboratories [5, 6]. Because there is no orbit for dipole magnet in the model calculation, a corrector with the same length is placed in the original position of the dipole. The calculation time is less than 1 hour at most. According to the calculation, the best result is selected as shown in Table 1. The closed orbit will reduce 2-3 mm by exchanging two magnets. After moving six magnets, the orbit is reduced to less than 2 mm, which is equivalent to the previous DC results. In order to reduce the risk, we can try to exchange 2 magnets first.

Table 1: Magnet Sorting Results

| Number of moving magnets | Minimum orbit | Maximum orbit |
|---|---|---|
| 0 | -4.83 mm | 5.65 mm |
| 2 | -2.81 mm | 2.11mm |
| 3 | -2.89 mm | 1.89 mm |
| 4 | -2.28 mm | 2.20 mm |
| 5 | -2.18 mm | 2.08 mm |
| 6 | -1.69 mm | 1.57 mm |

## CONCLUSION

In this paper, the differences of bare orbit and dipole field error between DC and AC mode are compared. It is found that the large horizontal orbit is mainly caused by the large AC dipole field error. In order to further reduce the horizontal orbit in the ring, a scheme of sorting the dipoles is proposed again. In order to reduce the risk of beam commissioning and time cost, the smaller orbit can be achieved by moving fewer magnets. The closed orbit distortion after moving 2 to 6 dipoles is calculated. After magnet sorting of dipoles, the orbit can be reduced by 3-4 mm, which reduces the difficulty of orbit correction. In terms of sorting effect and risk reduction, it is recommended to exchange 2 dipoles first.

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