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COMMISSIONING STATUS OF CSNS/RCS

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Abstract

The China Spallation Neutron Source (CSNS) is an accelerator-based science facility. CSNS is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy, striking a solid metal target to produce spallation neutrons. CSNS has two major accelerator systems, a linear accelerator (80 MeV Linac) and a 1.6 GeV rapid cycling synchrotron (RCS). The Beam commissioning of CSNS/RCS has been commissioned recently. Beam had been accelerated to 1.6 GeV at CSNS/RCS on July 7, 2017 with the injection energy of 61 MeV, and 1.6 GeV acceleration was successfully accomplished on January 18, 2018 with the injection energy of 80 MeV. The beam power achieved 25 Kw in March, 2018. The initial machine parameter tuning and various beam studies were completed. In this paper, the commissioning experiences are introduced.

INTRODUCTION

The Chinese Spallation Neutron Source (CSNS) is an accelerator-based science facility. CSNS is designed to accelerate proton beam pulses to 1.6 GeV kinetic energy, striking a solid metal target to produce spallation neutrons. CSNS has two major accelerator systems, a linear accelerator (80 MeV Linac) and a rapid cycling synchrotron (RCS). The function of the RCS accelerator is to accumulate and accelerate protons from the energy of 80 MeV to the design energy of 1.6 GeV at a repetition rate of 25 Hz [1, 2]. The Beam commissioning of CSNS/RCS has been commissioned recently. Beam had been accelerated to 1.6 GeV at CSNS/RCS on July 7, 2017 with the injection energy of 61 MeV, and 1.6 GeV acceleration was successfully accomplished on January 18, 2018 with the injection energy of 80 MeV. The beam power achieved 25 Kw in March, 2018.

PREPARATION FOR CSNS/RCS COMMISSIONING

Systematic preparation work was accomplished before the beam commissioning of CSNS/RCS, including systematic magnet measurements and beam dynamics study.

Magnet Measurements

Systematic magnet measurements were undertaken before the beam commissioning of CSNS/RCS to study the magnetic field characteristics of magnets at CSNS/RCS.

To reduce the magnetic field tracking errors, a method of wave form compensation for RCS magnets, which is based on transfer function between magnetic field and exciting current, was investigated on the magnets of CSNS/RCS [3]. There are one type of dipole named 160B and four types of quadrupoles, named 272Q, 253Q, 222Q and 206Q respectively at CSNS/RCS. Because of the differences of magnetic saturation and eddy current effects between these five types of magnets, there are magnetic field tracking errors between different magnets before wave form compensation, as shown in Fig. 1. The maximum magnetic field tracking error between the dipole and quadrupoles is larger than 2.5% over the ramping process. Wave form compensation was performed on all the magnets of CSNS/RCS. The magnetic field ramping functions for all the magnets were compensated to sine pattern. The maximum magnetic field tracking error between the dipole and quadrupoles was reduced from 2.5% to 0.08%, as shown in Fig. 2.

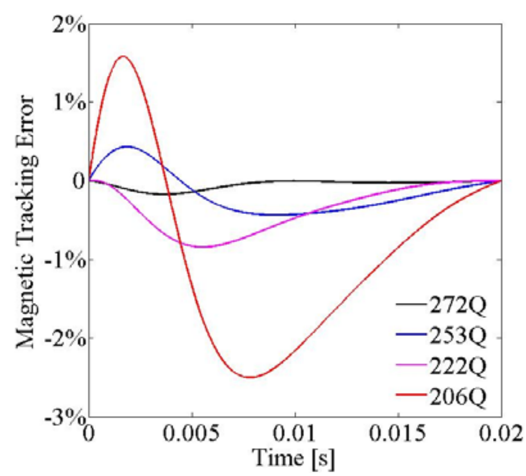

Figure 1: Magnetic field tracking errors between the dipole and four types of quadrupoles over the ramping process with no wave form compensation.

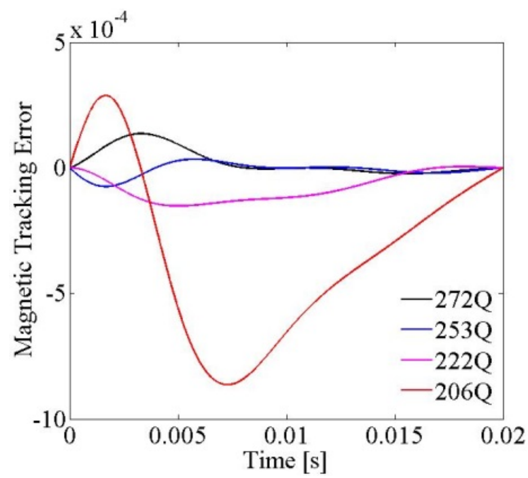

Figure 2: Magnetic field tracking errors between the dipole and four types of quadrupoles over the ramping process after wave form compensation.

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The core-to-core distance between magnets in CSNS/RCS is rather short in some places, as shown in Fig. 3. The fringe field interference results in integral field strength reduction. The integral gradient reduction of quadrupoles due to fringe field interference with adjacent magnets was accurately measured [4, 5]. The field measurement result shows that the integral maximum gradient reduction due to adjacent magnets can get up to 2.3%.

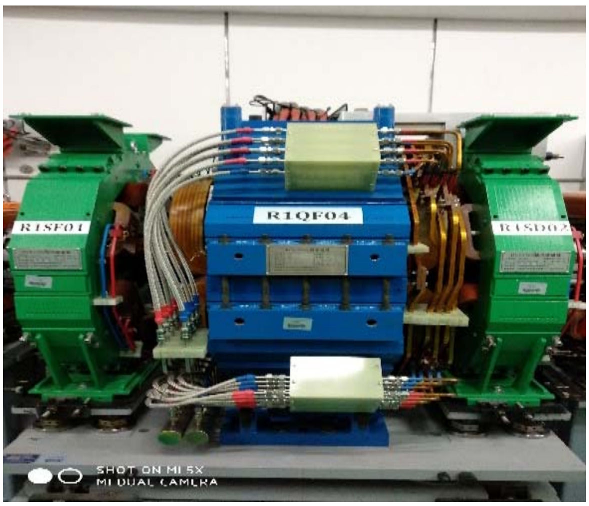

Figure 3: The layout of the Q222 and neighbor sextuple magnets.

Beam Dynamics Study

The lattice design of CSNS/RCS is based on hard edge model of quadrupoles. Because of the large aperture of quadrupoles, fringe field effect is an important issue. The systematic study of the effects of fringe field and interference of quadrupoles at CSNS/RCS was done using slicing model method before the beam commissioning. The betatron tune was matched to the design value taking into account fringe field effects and fringe field interference results for all quadrupoles.

For RCS, it is an important issue to match the dipole magnetic field ramping function with the RF frequency ramping function. The mismatch between the dipole magnetic field and RF frequency may induce serious synchrotron oscillation and large beam displacement at dispersion section. A new code was developed to study the dipole magnetic field and RF frequency tracking at CSNS/RCS.

STAGE Ⅰ BEAM COMMISSIONING

Because one klystron was sent back for repair, the Linac can only accelerate the beam to 61MeV in 2017. The Beam commissioning of CSNS/RCS was started in May 2017 with the injection energy of 61MeV.

To control the beam loss during the beam commissioning, the single shot beam mode was adopted. In the first step, the beam commissioning was started in DC mode without acceleration. On May 31st, the first beam was injected into the RCS, and successfully accumulated. After the optimization of B field, RF pattern and the injection, the beam transmission achieved 100% one day later. The measured tune is (4.856, 4.779), as shown in Fig. 4. The measured tune is very close to the design value (4.86, 4.78). The calculated fudge factors of quadrupoles are less than 1%, as shown in Fig. 5.

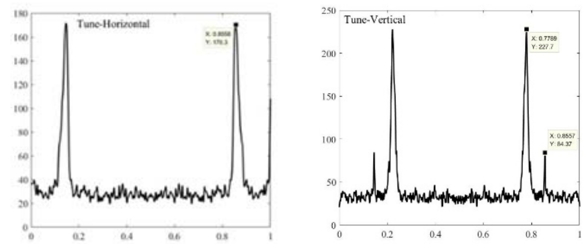

Figure 4: The measured tune of CSNS/RCS in DC mode.

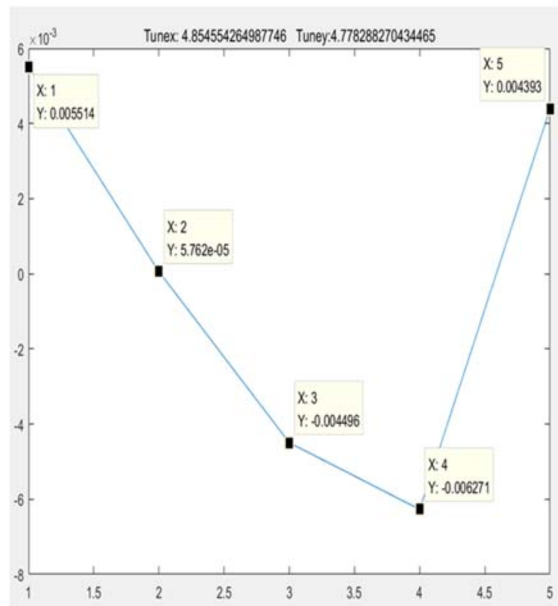

Figure 5: The measured fudge factors of quadrupoles.

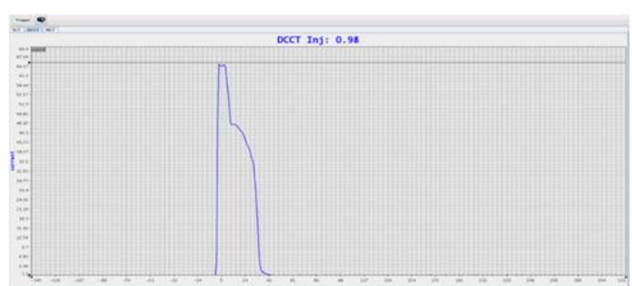

Figure 6: The beam current over one cycling period for the first beam shot in AC mode.

Beam commissioning in AC mode was started on July 7, 2017. The first beam shot was injected and accumulated successfully. However, the beam life time is only 4 ms, as shown in Fig. 6. The timing of magnet power supply and RF system were checked. The timing error of magnet power supply was about 140 µs. The beam was accelerated to the design energy 1.6GeV successfully after timing shift of magnet power supply. Then, the match between the dipole magnetic field and RF frequency were per-

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formed. The beam transmission achieved 100% on July 9, 2017.

STAGE Ⅱ BEAM COMMISSIONING

The Beam commissioning of CSNS/RCS was started on January 15, 2018 with the injection energy of 80MeV. At the beginning, beam commissioning was performed in DC mode. Beam was injected into the RCS, successfully accumulated for the first beam shot. The beam transmission rate got 100% after performing the match of dipole magnetic field and injection energy on the same day.

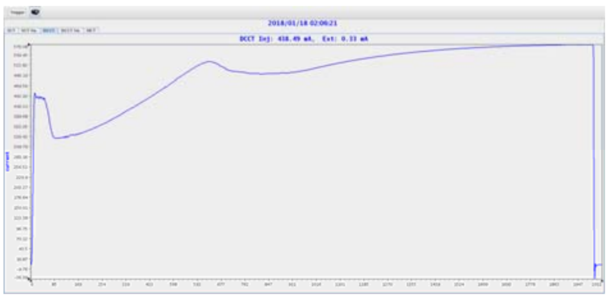

Figure 7: The beam current over one cycling period for the first beam shot in AC mode.

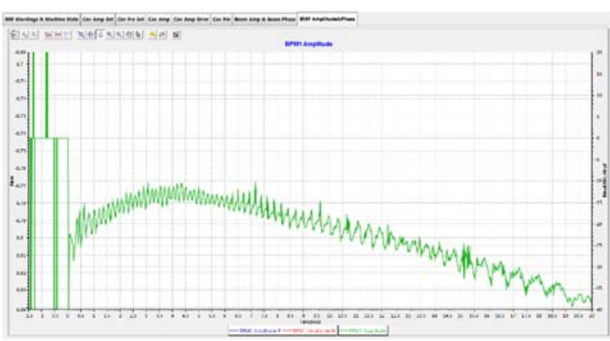

Figure 8: The beam displacement variation at dispersion section during acceleration process for the first beam shot.

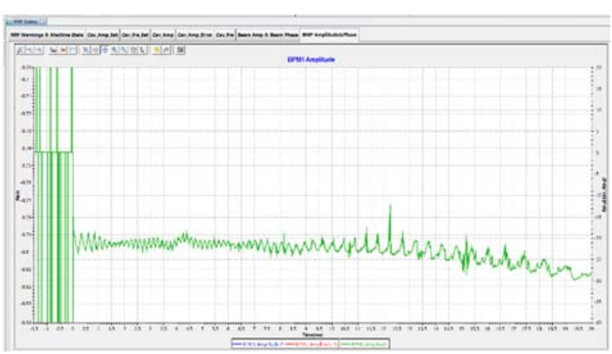

Figure 9: The beam displacement variation at dispersion section during acceleration process after the machine optimization.

The AC mode beam commissioning of CSNS/RCS with the injection energy of 80 MeV was started on January 18, 2018, and 1.6 GeV acceleration was successfully accomplished for the first beam shot. However there was serious beam loss, as shown in Fig. 7. The beam displacement at dispersion section was large and changed greatly during the beam acceleration, as shown in Fig. 8. The timing of magnet power supply at CSNS/RCS was shifted to match the injection beam, and the match of the bottom of dipole magnetic field and injection energy was performed. The RF frequency ramping function was optimized to match the dipole magnetic field ramping function. The beam transmission rate got 100% after the machine optimization on January 18, 2018. The beam displacement variation at dispersion section during acceleration process was greatly reduced, as shown in Fig. 9. The tune was measured during acceleration process over one cycling period. The measurement results are shown in Fig. 10. The variation of horizontal tune is less than 0.02, and the variation of vertical tune is about 0.04.

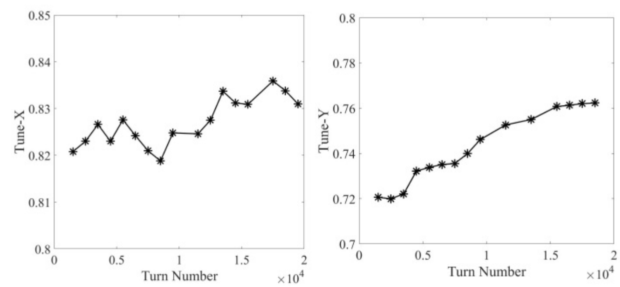

Figure 10: The tune variation during acceleration process over one cycling period.

CONCLUSION

Careful preparation work was performed before the beam commissioning of CSNS/RCS. Systematic magnet measurements were undertaken to study the magnetic field characteristics of magnets at CSNS/RCS. To reduce the magnetic field tracking errors at CSNS/RCS, a method of wave form compensation for RCS magnets, was investigated. The systematic study of the effects of fringe field and interference of quadrupoles at CSNS/RCS was done before the beam commissioning. Because of the careful preparation for beam commissioning, the beam commissioning of CSNS/RCS went very smoothly.

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