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FIELD MEASUREMENT OF THE QUADRUPOLE MAGNET FOR CSNS/RCS

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Abstract

The quadrupole magnets are being manufactured and measured for China Spallation Neutron Source Rapid Cycling Synchrotron (CSNS/RCS) since 2012. In order to evaluate the magnet qualities, a dedicated magnetic measurement system has been developed. The main quadrupole magnets have been excited with DC current biased 25Hz repetition rate. The measurement of magnetic field was mainly based on integral field and harmonics measurements at both static and dynamic conditions. This paper describes the magnet design, the field measurement system and presents the results of the quadrupole magnet.

INTRODUCTION

The China Spallation Neutron Source [1] is located in Dongguan city, Guangdong Province, China. The CSNS accelerator mainly consists of an 80Mev an H-Linac accelerator, a 1.6Gev Rapid Cycling Synchrotron (RCS) and two beam transport lines. CSNS linac output energy is chosen as 80 MeV in the first phase. The extraction energy of RCS is 1.6GeV at 25 Hz repetition rate. The CSNS/RCS project will be equipped 24 dipole magnets, 48 quadrupole magnets, 16 sextupole magnets and other corrector magnets. Among the dipole and the quadrupole magnets are excited with a repetition frequency of 25Hz.

MAGNET DESIGN

According to the size of the magnet aperture, there are four types of the quadrupole magnets. The main design parameters and the specifications of the quadrupole magnets are summarized in Table 1. The field quality of the magnets was required respectively for the higher order harmonics, the linear deviation and the integral field deviation.

The simulation environment employed in this study is OPERA-3D/Tosca [2].TOSCA was used for the integral field strength and the higher order harmonic components, It is also used to study the end fringing field and end chamfering of the magnets. The OPERA-3D/ELECTRA is used to the eddy current distribution in the magnet cores, in order to reduce the eddy current heating, some slits are cut in the end poles and end plates.

FIELD MEASUREMENT SYSTEM

A novel the magnetic field measurement device had been developed at IHEP. The prototype and the production quadrupole magnets were measured by this rotating coil measurement device and with different rotating coil. One magnet and the field measurement system are shown in Figure 1. The measurement system can be measured at both DC current and DC biased 25Hz AC exciting current.

Table 1: Main Design Parameters and Specification

Magnet type	RCS-QA	RCS-QB	RCS-QC	RCS-QD
Aperture	206mm	272mm	222mm	253mm
Effe. length	410mm	900mm	450mm	620mm
Max. gradient	6.6 T/m	5 T/m	6 T/m	6.35T/m
Unallowed multipole	5×10^{-4}	5×10^{-4}	5×10^{-4}	5×10^{-4}
Allowed multipole B_6/B_2 ,B_{10}/B_2	4×10^{-4} 6×10^{-4}	4×10^{-4} 6×10^{-4}	4×10^{-4} 6×10^{-4}	4×10^{-4} 6×10^{-4}
Lin. deviation	2%	1.5%	1.5%	1.5%

Figure 1: Quadrupole and Setup of the Rotating Coil.

Data Acquisition Device

Figure 2 shows the schematic layout of the magnetic field measurement system. It is commonly available based on National Instruments industrial standard. The signal acquisition card PXI-4462 is selected and provided with a wide dynamic range. The maximum sampling frequency is 204.8 KHz. A high precision motor control

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card PXI-7354 is used for the three motors movement and a digital I/O card PXI-6509 is used for the power supply control. These card are inserted at different slots of the PXI-1042 Chassis and they can work real-time fast communication through PTSI buses.

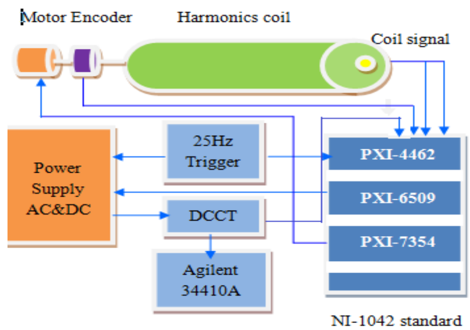

Figure 2: The Schematic Layout of the Rotating Coil.

Signal Processing

The magnetic field measurement program has been developed using graphical programming software package LabVIEW. The inductive voltage signals of the coil, the voltage signal (DCCT), the pulses of the angle encoder and the 25 Hz clock trigger signal were simultaneously obtained and recorded on channel 1, 2, 3 and 4 in 24-bit PXI-4462. The angle encoder generates 8192 revolution TTL level pulse signal. Every 16 encoder pulses are taken as an integral interval and 512 points of the integration value are acquired each period [3]. The sampled data must be prepared at least up to the angle of 2π. Then Fourier transformation of this sampled data gives multipole fields at this timing.

MEASUREMENT COILS

Coil Parameter

The rotating coils were specifically developed with DC current and DC biased 25Hz AC current in two modes. There are two rotating coils for the four lengths of the quadruple magnets, the effective length of the each rotating coils is 2000 mm and 1600mm with a maximum outer radius of 88mm and 112mm, respectively. The outward coil is used to measure the main field and the higher order time-dependent multipole field respectively when the DC field and DC biased 25Hz AC field are measured, the signals are leaded with a different number of turns. The higher order harmonic of the DC field is measured by two winding coils connected in series opposition, which can compensate the rejection of the dipole and quadrupole components.

Construction Design

The rotating coil are based on the radial winding geometry technique, which included a compensated and an uncompensated coil in two modes. The length of the coil is enough to cover the edge field of the magnet, the coils are made of glass-fiber reinforced epoxy (G10). The sleeve are also used by G10 material. The cross section of the harmonics coil assembly is shown in Figure 3, green color represents the epoxy fiberglass material, red color represents the groove of the G10 bar, the multifilar wire was wound on the groove, and 4 precisely placed grooves carry 2 sets of winding for the inward coil and outward coil.

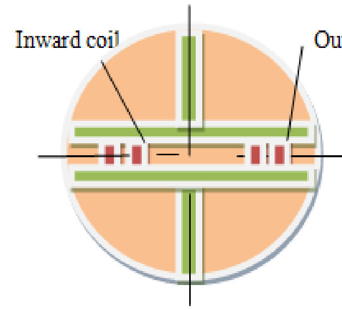

Figure 3: Cross Section of the Harmonics Coil.

MAGNETIC MEASUREMENT RESULTS

The magnetic field measurement of each quadrupole magnet includes the DC and DC biased 25Hz AC modes. Four magnets will be measured by Hall Probe, with one magnet of each type aperture. For the DC field measurement, mainly includes higher order components and the integral field transfer function in the reference radius. For the DC biased 25Hz AC field measurement, mainly includes higher order time-dependent multipole fields and the integral field transfer function. The deviation of the integral field gradient of the magnets at DC biased 25Hz Ac mode is not explored.

Magnetic Field Measurement for the Static Field

The quadrupole magnets have been measured with a rotating coil to get the higher order multipole errors and the integrated field strength as a function of the current. Digital bucking technology was used for a more precise evaluation of the higher order harmonics components.

The magnet was standard cycle three times to obtain reproducibility of the hysteresis before field measurement. The magnet was ramped to maximum current that is above the operating current 10%. The integral excitation curve was measured from injection energy of 80MeV to 250MeV, other was measured from 80Mev to 1.6GeV. The nonlinear of saturation property is less than 1.35% from the injection to the extraction energy**.** The higher order multipole components were performed and the data were analysized at the reference radius of the injection (99mm) and the extraction of energy (123mm), respective. Figure 4 (a) shows the transfer function in the two cases, (b) shows the harmonic errors at a reference radius of 123mm.

The integrate field, 2-D field distribution and excitation curve were measured by Hall Probe measurement system.

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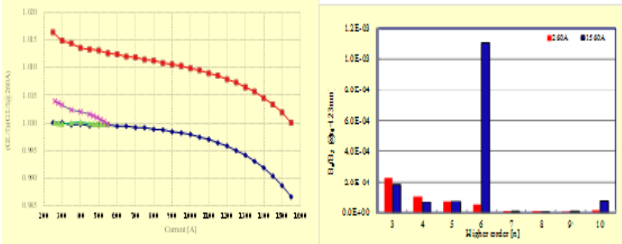
The quadrupole field strength of the harmonics coil is calibrated along Z direction by Hall probe.



(a) (b)

Figure 4: Transfer Function at 80Mev and 1.6Gev (a), Higher Order Multipole Components (b).

Higher Order Time-Dependent Multipole Field

The integrated magnetic field and the higher order time-dependent multipole fields were measured with an alternating current pattern of 25Hz with DC biased. The time-dependent multipole fields can be decreased down to 5E-4 by the harmonics injection compensation techniques.

Table 2：Harmonics Compensation Results

Harmonics Components(Hz)	Before Harmonics	After Harmonics
25	1	1
50	7.73E-03	1.69E-04
75	1.91E-03	2.14E-04
100	4.34E-03	8.46E-05
125	9.10E-05	3.71E-05
150	4.99E-05	4.84E-05
175	4.24E-05	4.86E-05

Table 2 shows the comparison of the time-dependent multipole fields before and after the current harmonic compensation at 895dc+638ac. The nonlinearity of the saturation property is about 3.3%. The quadrupole (QB) have borne 72 hours full AC excitation current test.The average temperature of the iron core is about 80°C, the maximum temperature is 138.6°C around nuts at the pole end.

CONCLUSIONS

One magnet of four types was fabricated and the field measured of DC current and DC biased 25Hz AC excitation heating test has been finished. The data of the first three quadrupole magnets of QB type showed that the deviation of the integral field was less than 1.2×10^{-3}. For the eddy current heating test, the maximum temperature is ~100°C for QA and QC type magnets. The temperature of QD type is similar to the QB magnet. The field measurement of the mass production magnets will start in May of 2014 and will end in July 2015.

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