Magnetic Field Measurement and Analysis of the CSNS/RCS Quadrupole Magnets

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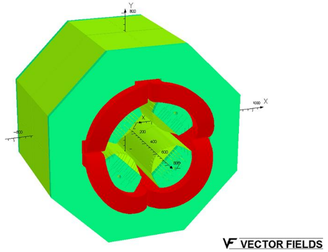
Background

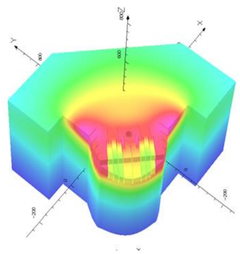
The China Spallation Neutron Source (CSNS) is under construction at Dongguan city, Guangdong province, China. The CSNS accelerator mainly consists of an 80Mev H^- Linac, a 1.6Gev Rapid Cycling Synchrotron (RCS) and two beam transport lines . The RCS includes 48 quadrupole magnets and the quadrupole magnets are excited by 25Hz AC biased DC current. Each magnet has been measured by DC current, AC+DC current and the compensation of time harmonic errors. All of the quadrupole magnets have been installed in the tunnel at the end of 2016. The project will be completed in March 2018 in the first phase.

Magnet

3D Simulation Model



Temperature Distribution



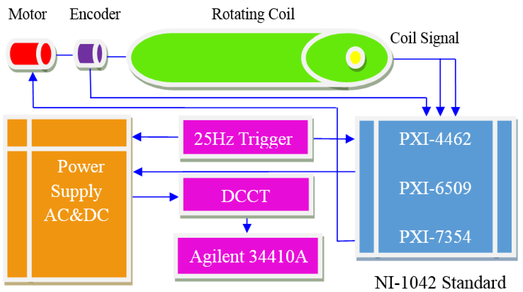
The maximum temperatures is 138℃ for large aperture magnet.

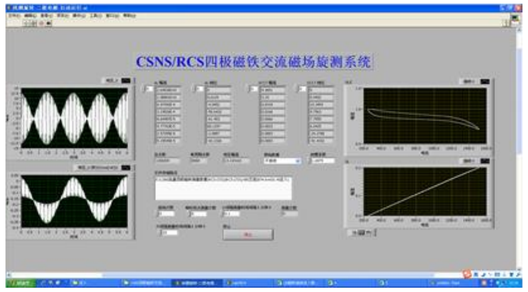
Main Parameters of the Four Type Quadrupole Magnets

Magnet type	RCS-QA	RCS-QB	RCS-QC	RCS-QD
Aperture (mm)	206	272	222	253
Effective length (mm)	410	900	450	620
Max. gradient (T/m)	6.6	5.0	6.0	5.35
DC current (A)	813	895	859	829
AC current (A)	580	638	612	591
Unallowed multipole (@ r_0)	5×10^{-4}	5×10^{-4}	5×10^{-4}	5×10^{-4}
Allowed multipole (@ r_0)	4×10^{-4}	4×10^{-4}	4×10^{-4}	4×10^{-4}
(B_6/B_2 ,B_{10}/B_2)	6×10^{-4}	6×10^{-4}	6×10^{-4}	6×10^{-4}
Field non-linearity	2%	1.5%	1.5%	1.5%
Field deviation magnet to magnet	$\pm2\times10^{-3}$	$\pm2\times10^{-3}$	$\pm2\times10^{-3}$	$\pm2\times10^{-3}$
Quantity	16	16	8	8

Schematic Layout and Measurement Device

Schematic Layout for the Rotating Coil System





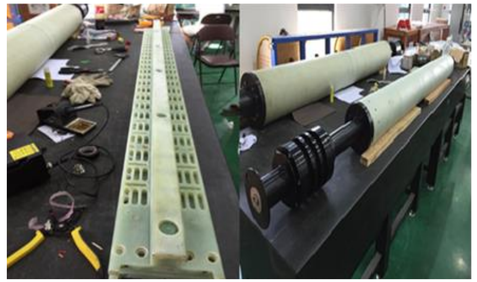
Rotating Coil Measurement System

The measurement system consists of the following sections:

- Data acquisition.
- Harmonic coil and rotating coil.
- 25 Hz trigger signal card
- Supporting adjust platform.
- The software development in LabVIEW
- Alignment equipment (level, theodolite).
- An annular encoder, Servo motors and the power supply.

Rotating Coil

Harmonics Coil

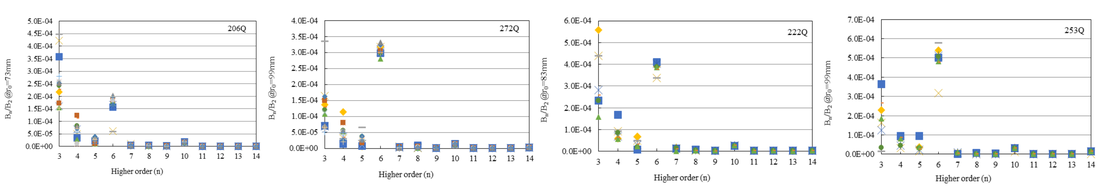


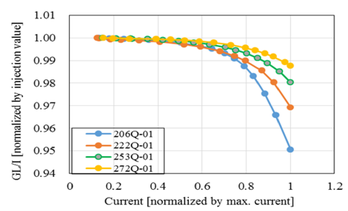
Coil Parameters

Item	RCS-QA/QC(DC)	RCS-QB/QD(DC)	RCS-Q(AC&DC)
Magnet aperture (mm)	206/222	272/253	206/222/253/272
Magnet length (mm)	410/450	900/620	410/450/620/900
r1 (mm)	88	112	80
r2 (mm)	60.87	77.47	-
r3 (mm)	-74.8	-95.2	-60
r4 (mm)	-47.67	-60.67	-
Main coil (turns)	200	120	32
Bucking coil (turns)	300	180	-
E2 (V)	1.5	2	13.5
Coil length (mm)	1600	2000	2000

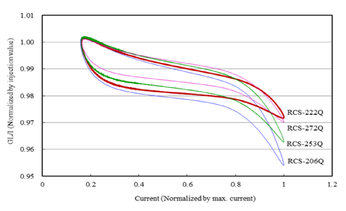
- Coil framework Material: epoxy fiberglass.
- Multifilar Wire: 20 Multifilar, MWS.
- Tolerance: 0.02mm.

Magnetic Field Results

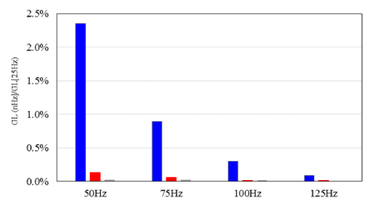




The field nonlinearity of DC current for four families of the quadrupole magnets are 1.3%, 2.1%, 3.0% and 5.2% .



The nonlinearity of AC+DC current for four kinds of magnets are about 3.0%, 4.0%, 3.0% and 4.7% respectively.



- The measurement reproducibility of the phase of 25Hz AC field reached 0.05º.
- The compensation can be reduced from 2.35×10^{-2} to 2.47×10^{-4} for 50Hz.

Conclusion

An innovative rotating coil magnetic field measurement system had successfully been developed to measure the field of CSNS/RCS quadrupole magnets excited by 25Hz AC biased DC current. The field measurement precision of the system were good enough to meet the measurement requirements. Three long rotating coils with large diameters were designed and manufactured. All quadrupole magnets categorized into four families had been tested and measured in both DC and DC+AC modes in 2015. The AC field transfer functions of every magnet were precisely measured and the technique of current harmonic injection could suppress the field harmonics of the magnet down to 5×10^{-4}.

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