SUMMARY OF FIELD QUALITY OF TPS LATTICE MAGNETS

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Abstract

A modern 3-GeV synchrotron radiation source under construction at NSRRC is named Taiwan Photon Source. Great quality of magnets is required to maintain the electron beam in the required orbit in the storage ring and the booster ring. The mechanical performance and the magnetic field of these magnets were fully inspected at NSRRC. The standard deviation of the integral field strength of 48 SR dipole magnets is better than 0.07 %. The integral fields, multipoles and center offsets of the 240 SR quadrupole and 168 SR sextupole magnets conform to strict specifications. The field character of a BR combined-function dipole magnet was analysed with a differential method; the standard deviation of the field strength of 54 BR dipole-magnets is better than 0.15 %. The field quality of 36 BR pure quadrupole and 48 BR combined-function quadrupole magnets are acceptable to conform to the requirements of the booster ring. The field strength and multipole errors of 24 BR sextupole magnets were also examined. The detailed magnetic performance of the lattice magnets are discussed in this report.

INTRODUCTION

Taiwan Photon Source (TPS) is under construction at National Synchrotron Radiation Center (NSRRC). The magnets of the storage ring (SR) and the booster ring (BR) are constructed in the same tunnel. In total, 641 magnets are contracted out and manufactured (exclude the quadrupole magnet in the long-straight section). The 96.2 % of fabricated magnets are installed in the SR and BR. Only 3.8 % of magnets for the spare. These precise lattice magnets have been fully examined with a Hall-probe measurement system (HPS), rotating-coil measurement system (RCS) and 3D coordinate measuring machine (CMM). The HPS was used to map the local and integral fields of the dipole magnet. The quadrupole and sextupole magnets of SR have their mechanical centers adjusted via a foot-shim method and were inspected with the CMM [1]. The magnetic center of the magnet was detected with the RCS after shimming the mechanical center. The multipole errors of the quadrupole and sextupole magnets of the SR have been corrected with the yoke-shim and pole-shim methods, respectively [1].

PERFORMANCE OF THE TPS LATTICE MAGNET

SR-Dipole Magnet

The SR-DM magnet has a return yoke of H-type of which the rigid structure provides a homogeneous dipole field [2]. The dipole magnets of types I and II have the same physical iron yokes but with different foot-support angles so as to match the girder angles 7.5^o and -7.5^o. The magnetic length and pole gap of SR-DM magnet is 1100 mm and 46 mm, respectively. Figure 1 displays the b_0L distribution and field dispersion of the SR-DM magnet with charged current 615 A. The mean value ± standard deviation (σ) of b_0L of the SR-DM magnet are -1.3201 ± 0.0009 T·m, respectively. The field dispersion of b_0L is better than ±0.16 %. Figure 2 displays the normalized multipole (B_nL/B_0L) of the SR-DM magnet with normalization at 25 mm. Here, n denotes the multipole index; n=0 signifies the dipole term. The mean value and of the measured multipoles agree with the TOSCA simulation at 615 A.

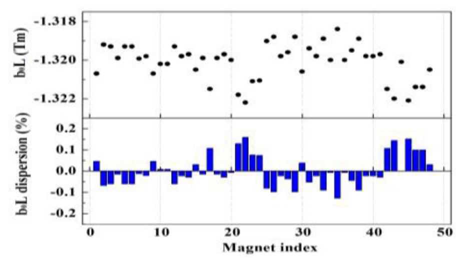

Figure 1: b_0L distribution and dispersion of the SR-DM magnet.

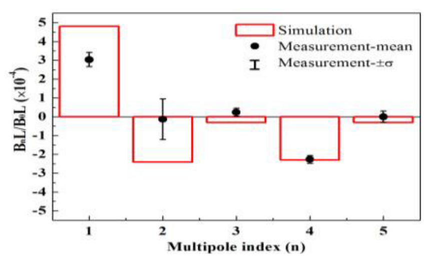

Figure 2: Simulation and measurement of normalized multipoles of the SR-DM magnet.

SR-Quadrupole Magnet

The quadrupole magnet of SR has varied cuts on the iron yoke to fit the shape of the vacuum chamber [2]. The magnetic length of SR-short-QM and SR-long-QM are 300 and 600 mm, respectively. The bore diameter of SR quadrupole magnet is 74 mm. The pole profile of the SR-short-QM and SR-long-QM magnets are manufactured with a wire-cutting technique and computer-numerical-control (CNC) machining, respectively. Figures 3 (a) and (b) display the normalized multipoles of the SR-short-QM and SR-long-QM magnets, respectively, with charged current 180 A. The B_nL/B_1L (A_nL/B_1L) is a normalized normal (skew) multipole with normalization at 25 mm of the GFR. The mean value and of these multipoles meet the specification requirements. The mean value ± σ of b_1L of 192 SR-short-QM and 48 SR-long-QM magnet is

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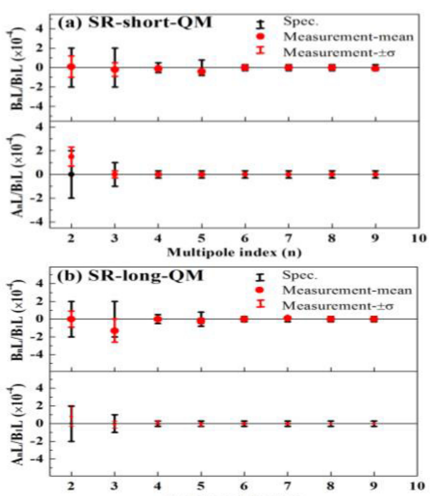
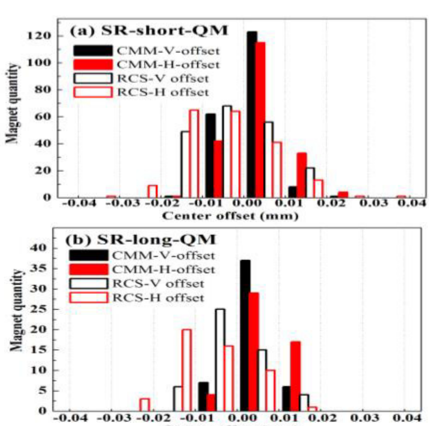
5.2160 ± 0.0086 T and 9.4498 ± 0.0160 T, respectively. The integral field strength of the quadrupole magnet will be fine-tuned with an independent power supply. Figures 4 (a) and (b) display the distribution of the mechanical and magnetic-center offset of the SR-short-QM and SR-long-QM magnets. The CMM-V-offset (RCS-V-offset) and CMM-H-offset (RCS-H-offset) indicate the vertical and horizontal offsets, respectively, of the mechanical (magnetic) offset that was measured with the CMM (RCS). The mechanical-center offset was shimmed approximate ±0.01 mm using a CMM in both vertical and horizontal directions. The vertical and horizontal offsets of the magnetic center were detected with the RCS after CMM shimming. The mean value ± σ of CMM-V-offset and CMM-H-offset of 192 SR-short-QM (48 SR-long-QM) magnets is -2 ± 4 μm (-5 ± 5 μm) and -5 ± 6 μm (-7 ± 5 μm), respectively. The mean value ± σ of RCS-V-offset and RCS-H-offset of 192 SR-short-QM (48 SR-long-QM) magnets is 3 ± 9 μm (2 ± 7 μm) and 6 ± 11 μm (8 ± 10 μm), respectively. Moreover, the mean value of mechanical and magnetic tilt of the SR quadrupole magnets is better than 0.01°, respectively.



Figures 3: (a) and (b) display the normalized multipoles of SR-short-QM and SR-long-QM magnets, respectively.



Figures 4: (a) and (b) display the center offsets of 192 SR-short-QM and 48 SR-long-QM magnets, respectively.

SR-Sextupole Magnet

The top and bottom central poles of the sextupole magnet were designed to be movable for a multipole correction. The magnetic length and bore diameter of SR-SM magnet is 250 mm and 78 mm, respectively. The multipole error of a sextupole magnet was corrected with the pole-shimming method for the central pole [1, 2]. Figure 5 displays the normalized multipoles of 168 SR-SM magnets with normalization at 25 mm and charged current 150 A. These multipoles of SR-SM magnet meet the specification requirements. The mean value ± σ of b_2L of 168 sextupole magnets is 60.108 ± 0.153 T/m. The field variation of sextupole magnet is caused by the multipole correction via a pole-shim method, the inaccuracy of the bore radius and the variation of the yoke length. The integral field strength of the sextupole magnet will be fine-tuned with an independent power supply. Figure 6 displays the mechanical-center and the magnetic-center offsets of the SR-SM magnets. The mechanical offset is shimmed approximate ±0.01 mm in vertical and horizontal directions. The mean value ± σ of CMM-V-offset and CMM-H-offset of 168 SR-SM magnets is -2 ± 4 μm and -5 ± 5 μm, respectively. The mean value ± σ of RCS-V-offset and RCS-H-offset of 168 SR-SM magnets is 5 ± 8 μm and 5 ± 9 μm, respectively. Moreover, the mean value of mechanical and magnetic tilt of the 168 SR-SM magnets is better than 0.01°.

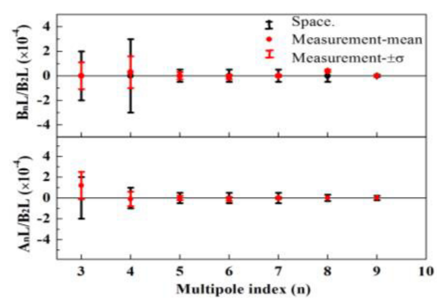


Figure 5: Normalized multipoles of 168 sextupole magnets.

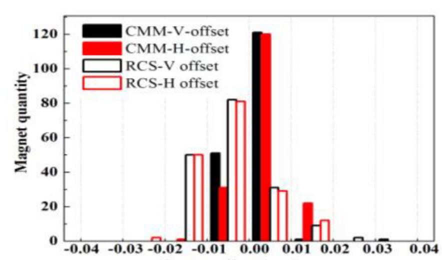


Figure 6: Mechanical- and magnetic-center offsets of SR-SM magnets.

BR-Dipole Magnet

The BR-BD and BR-BH are combined-function dipole magnets that contain quadrupole and sextupole components [3]. The effective lengths of the BR-BD and the BR-BH are 1600 and 800 mm, respectively. These magnets were mapped with the HPS system and analysed

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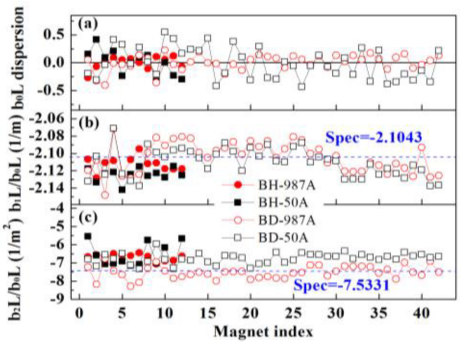
with a differential method [4]. Figures 7 (a), (b) and (c) display the b_0L dispersion and component ratios of the BR-BD and BR-BH magnets with charged currents 987 A and 50 A. The mean value ± σ of b_0L of the BR-BD (BR-BH) magnet is -1.3173 ± 0.0019 T·m (-0.6589 ± 0.0007 T·m), with charged current 987 A.



Figures 7: (a), (b) and (c) display the b_0L dispersion, b_1L/b_0L and b_2L/b_0L of 12 BH and 42 BD magnets with charged currents 987 A and 50 A.

BR-Quadrupole Magnet

The BR quadrupole magnet includes pure (BR-QP) and combined-function (BR-QF) types that differ in their pole profiles [5].

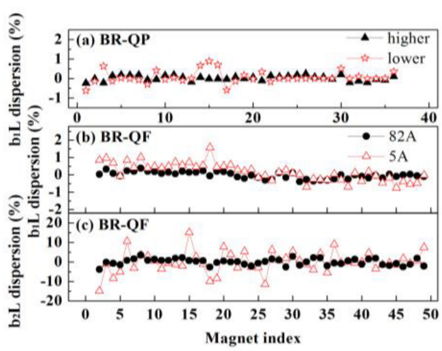
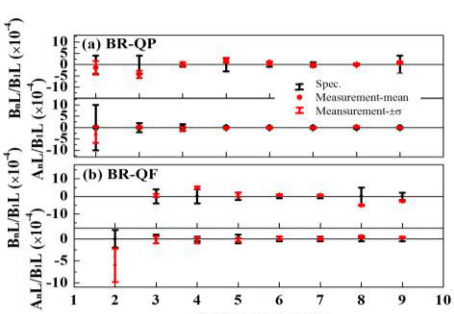


Figure 8: (a) displays the b_1L dispersion of 36 BR-QP magnets. Figures (b) and (c) display the b_1L and b_2L field dispersion of 48 BR-QF magnets, respectively.



Figures 9 (a) and (b) display the normalized multipoles of 36 BR-QP and 48 BR-QF magnets, respectively.

The combined-function magnet also supports a sextupole component in the magnet. The BR-QP magnets have three types with varied coil turns and are named BR-QP-Q1 (18 coil turns), BR-QP-Q2 (12 coil turns) and BR-QP-QM (6 coil turns) magnets. Decreasing the coil turns increases the minimum ramping current of the BR-QP-Q2 and BR-QP-QM magnets. Increasing the minimum ramping current of magnet avoids the ripple and instability of excited current in the lower current region. The BR quadrupole magnet was measured with the RCS system with normalization at 15 mm GFR. Figure 8 (a) displays the b_1L dispersion of the 36 BR-QP magnets that include BR-QP-Q1, BR-QP-Q2 and BR-QP-QM magnet. The higher (lower) current indicates 104 A (5 A), -99 A (-5 A) and -90 A (-5 A) for the BR-QP-Q1, BR-QP-Q2 and BR-QP-QM magnets, respectively. The mean value ± σ of b_1L of 12 BR-QP-Q1, 12 BR-QP-Q2 and 12 BR-QP-QM magnets is 4.293 ± 0.005 T, -2.720 ± 0.004 T and -1.232 ± 0.002 T, respectively. Figures 8 (b) and (c) display the b_1L and b_2L dispersions of the BR-QF magnet with charged currents 82 A and 5 A. The mean values ± σ of b_1L and b_2L of 48 BR-QF are 3.361 ± 0.006 T and 3.697 ± 0.063 $T \cdot m^{-1}$, respectively, with charged current 82 A. The field dispersion of the lower current is larger than of the higher current, because the remnant field has an influence at a lower current. Figures 9 (a) and (b) display the normalized multipoles of the BR-QP and BR-QF magnets, respectively.

BR-Sextupole Magnet

The mean value ± σ of b_2L of 24 BR-SM magnets is 21.008 ± 0.058 T/m. The normalized multipoles of BR-SM magnets meet operating requirements.

SUMMARY

The SR and BR magnets were manufactured and fully inspected at NSRRC. The 96.2 % of fabricated magnets are installed in the SR and BR. The field quality of SR and BR magnets meets the requirements of TPS operation. All magnets are installed as of April 2014. The water piping and power connection of the SR and BR magnets are in process. The water piping and power connection of the SR and BR magnets are in process. Both rings will be commissioned at the end of 2014.

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