CHARACTER AND PERFORMANCE OF MAGNETS FOR THE TPS STORAGE RING *

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Abstract

Taiwan Photon Source (TPS) is a third-generation light source under construction at the National Synchrotron Radiation Research Center (NSRRC). The orbit of the electron beam will be controlled with 48 dipole, 240 quadrupole, 168 sextupole and several corrector magnets in the storage ring. The construction of the first magnets for one sector, including the prototype magnets, is to be completed during 2011 December. The mechanical dimensions of these magnets have been examined with a precise 3D-coordinate-measuring machine (CMM). The field strength, effective length and multipole errors are inspected with a rotating-coil measurement system (RCS) and a Hall-probe measurement system (HPS). The mechanical center of the quadrupole and sextupole magnets is adjusted with a precise shimming block on the CMM bench. The inaccuracy of the position of the mechanical center will be within 0.01 mm after shimming the feet. In this paper we report the current status, the construction performance, the mechanical shimming algorithm and related issues for the construction of the highly precise magnets.

INTRODUCTION

Taiwan Photon Source (TPS) is a photon facility with great brightness and small emittance. Magnets of high quality are required to achieve precise control of the trajectory of the electron beam in the storage ring. Several studies of magnet technology include their design, manufacture and measurement [1-2]. The examination of the first magnets of one section, called first magnets, will yield an understanding of the mechanical precision and the field performance of the prototype magnets. The first magnets include dipoles, short-quadrupole (short-QM), long-quadrupole (long-QM), standard sextupole (S1), mid-wide sextupole (S2) and wide sextupole (S3) magnets [3]. The short-QM (or long-QM) magnets have several cross sections and varied shapes of the yoke with magnetic length 300 mm (or 600 mm). The short-QM magnets include Q1, Q5, R4Q8, Q6 and Q10 magnets; the long-QM magnets include Q2 and Q9 magnets. The magnetic length of the sextupole magnets is 250 mm. The quadrupole and sextupole magnets, called multipole magnets, are to adjust the mechanical offset of the magnet center within 0.01 mm via a feet-shimming method on the 3D-coordinate-measurement system (CMM) [3]. The center of the magnetic field will be measured with a rotating-coil system (RCS) after the feet shimming.

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MAGNET PRODUCTION AND EXAMINATION

The production and examination of TPS storage-ring magnets involve a collaboration of NSRRC and Buckley Systems Ltd. (BSL). The procedure to produce magnets involves (i) manufacture of the magnets with shimming the mechanical center-offset within 0.03 mm using a CMM at the BSL site, (ii) testing the field quality by NSRRC staff and equipment at the BSL site, (iii) shipping, (iv) shimming the mechanical center-offset within 0.01 mm using a CMM at the NSRRC site, and (v) a thorough examination of the quality of the magnetic field at the NSRRC site.

DIPOLE MAGNET PERFORMANCE

The advantages of the dipole magnet having a structure of H type include high symmetry and small deformation. The nominal operating current of dipole magnet is 615 A with integral field 1.3101 T·m [4]. Figures 1 (a), (b) and (c) display the integral IB-curve, center-field homogeneity ($\Delta B/B0$) and effective length (L_{eff}) of a DM-P01 magnet. The integral field strength, I0, is situated over 600 A. The field homogeneity of DM-P01 magnet is better than 5×10^{-5} at 615 A in the good field region. The effective magnetic length of this DM-P01 magnet is 1095.5 mm, slightly shorter than specification 1100 mm, at 615 A.

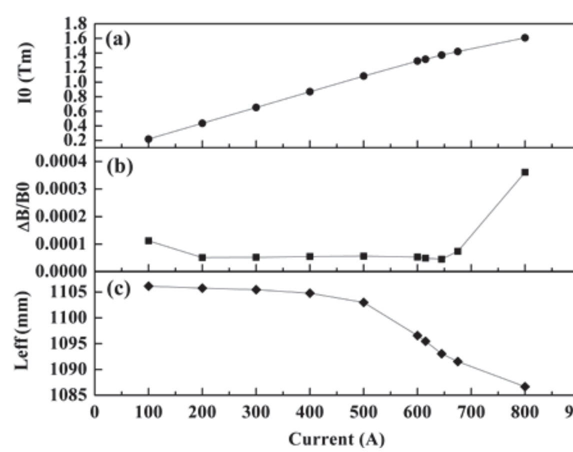

Figure 1: (a) integral IB-curve, (b) field homogeneity of the center line and (c) effective length of a DM-P01 magnet which is as a function of the excitation current.

Figure 2 displays the integral combination-field of DM-P01 when the main and the trim coils are excited simultaneously. The main coil is excited to 615 A; the

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trim coil has a variable current. The left and right axes of Fig. 2 display the integral field and the increase ratio of integral field, respectively. The integral field is increased to 529 G or 4.02 % when the trim coil is excited from 0 to 7 A. The dashed line is a linear fit of the integral field with slope 0.00756. The performance of the trim coil is hence 75.6 G·m/A of coil charge.

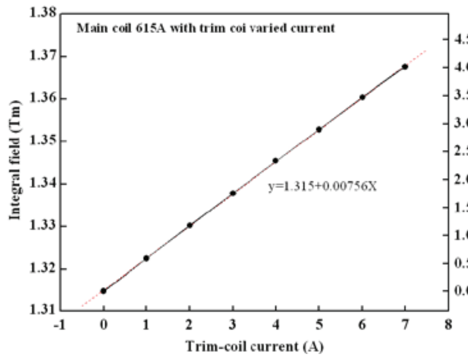

Figure 2: Integral combination-field from combining main and trim coils of a DM-P01 magnet. The left and right axes display the integral field and field-increase ratio, respectively.

CENTER OFFSET OF MULTIPOLE MAGNETS

The mechanical center and the magnetic field center of the quadrupole and sextupole magnets were measured with a CMM and a RCS, respectively. Several points were measured by CMM at both sides and indicate the mechanical center of the magnet. This mechanical center of the magnet was shimmed within 0.01 mm via a precise feet-shimming block on the CMM. The pole height of the magnet was detected to avoid a magnet tilt during feet shimming. The magnetic center of a magnet is measured with a RCS when the feet shimming is finished. The horizontal offset of the magnet was measured with a both-side method of a RCS [5]. Calibration of the vertical-offset measurement of RCS was done with a statistic results from CMM and RCS. Figure 3 displays the mechanical-center and magnetic-center offset of the quadrupole and sextupole magnets. The mechanical center offset was shimmed within ±0.007 mm using a CMM in vertical and horizontal directions. The average absolute values of the vertical-center and horizontal-center offsets are both 0.003 mm. The average absolute values of the vertical-center and the horizontal-center offsets of the RCS are 0.011 mm and 0.020 mm, respectively. The discrepancies of the average offset between the CMM and RCS are 0.008 mm and 0.017 mm in the vertical and horizontal directions, respectively. The magnet tilt was decided by the pole-height measurement at both sides of the CMM and the normalization between normal- and skew-multipole terms of the RCS. The average absolute values of the tilt of multipole magnets are 0.01° and 0.02° measured with the CMM and RCS, respectively.

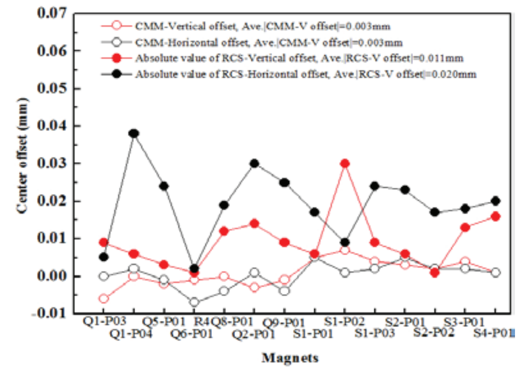

Figure 3: Center offsets of multipole magnets measured with the CMM and RCS.

FIELD QUALITY OF MULTIPOLE MAGNETS

Figures 4 (a) and (b) display the integral-field strengths of quadrupole and sextupole magnets measured with the RCS. The amplitude of the integral-field measurement of the RCS unit was calibrated with the HPS and a NMR probe. The average integral fields of the short-QM and long-QM are -5.238 T and -9.515 T at 180 A, respectively. The maximum deviations of the nominal integral field of the short-QM and long-QM are 0.5 % and 0.1 %, respectively. The nominal integral fields calculated (TOSCA software) of the short-QM and long-QM are -5.1 T and -9.378 T at 180 A, respectively [4]. Figure 4 (b) displays the average integral field of sextupole magnets to be 121.02 T/m at 150 A with maximum deviation 0.3 %. The nominal field of a sextupole magnet is 119.5 T/m at 150 A. The measured average integral fields of the short-QM, long-QM and sextupole magnets are larger than the calculated field by approximately 2.7 %, 1.4 % and 1.3 %, respectively.

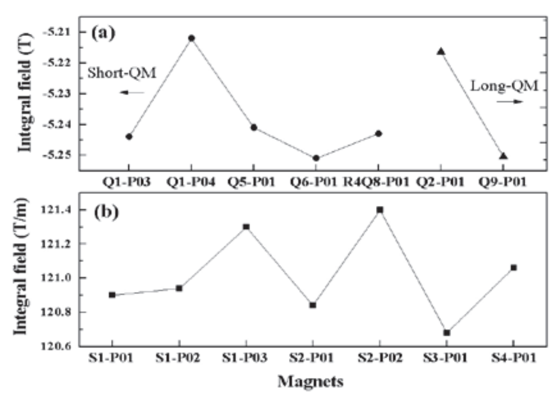

Figure 4: Integral field of (a) quadrupole and (b) sextupole magnets.

Figures 5 (a) and (b) display the normalized normal (B_n/B_m) and skew multipoles (A_n/B_m) of quadrupole magnets, respectively. Q1-P03, Q1-P04, Q5-P01, Q6-P01 and R4Q8-P01 magnets are the short-QM magnets. Q2-P01 and Q9-P01 magnets are the long-QM magnets [3]. The average normalized multipoles B_2/B_1 (A_2/B_1), B_3/B_1 (A_3/B_1), B_4/B_1 (A_4/B_1) and B_5/B_1 (A_5/B_1) are 1.2×10^{-4}

(1.1×10^{-4}), -0.7×10^{-4} (0.3×10^{-4}), -0.2×10^{-4} (-0.4×10^{-4}), -0.6×10^{-4} (0), respectively.

Figures 6 (a) and (b) display the normalized normal and skew multipoles of sextupole magnets, respectively. S1-P01, S1-P02, S1-P03 and S4-P01 are standard sextupole magnets; S2-P01 and S2-P02 are mid-width sextupole magnets, and S3-P01 is the wide sextupole magnet [3]. The center poles of the sextupole magnets have a precise pole shim to allow adjustment and to decrease the B_4/B_2 multipole error. The average normalized multipoles of B_3/B_2 (A_3/B_2), B_4/B_2 (A_4/B_2), B_5/B_2 (A_5/B_2), B_6/B_2 (A_6/B_2), B_7/B_2 (A_7/B_2) and B_8/B_2 (A_8/B_2) are -0.3×10^{-4} (1.0×10^{-4}), 2.8×10^{-4} (0), -0.1×10^{-4} (-0.1×10^{-4}), 0.1×10^{-4} (0), 0.1×10^{-4} (0), 0.2×10^{-4} (0), respectively.

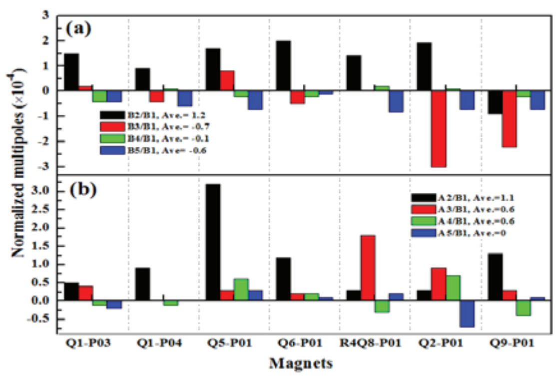

Figure 5: (a) Normalized normal and (b) skew multipole of quadrupole magnets.

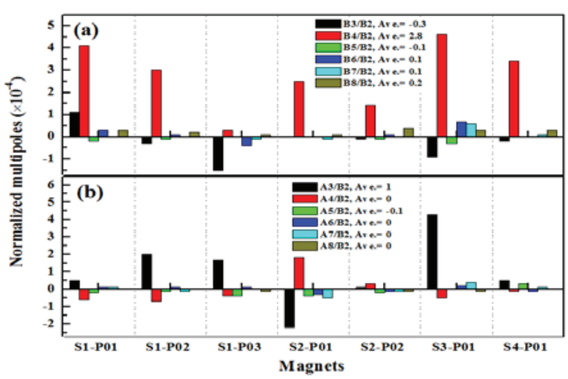

Figure 6: (a) Normalized normal (b) skew multipole of sextupole magnets.

A high-current examination of dipole (DM-P01), short-QM (Q1-P04), long-QM (Q2-P01) and sextupole (S4-P01) magnets was made to meet the future 3.5-GeV energy upgrade requirements of TPS. The required integral-field strength of magnets increases 16.7 % when the electron-beam energy upgrades from 3-GeV to 3.5-GeV. Figure 7 displays the normalized multipoles of DM-P01, Q1-P04, Q2-P01 and S4-P01 magnets in the 3-GeV and 3.5-GeV conditions. The results demonstrate that these magnets can operate at 3.5 GeV as well as at 3 GeV.

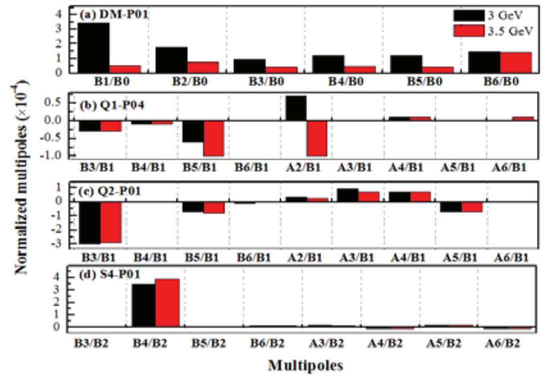

Figure 7: Normalized multipoles of (a) DM-P01, (b) Q1-P04, (c) Q2-P01 and (d) S4-P01 in 3-GeV and 3.5-GeV conditions.

SUMMARY

The first magnets of the dipole magnet have a uniform field with homogeneity better than 5×10^{-5} at 615 A. The trim coil has a correction field 75.6 G·m/A. The average absolute offset of the mechanical center was shimmed within 0.003 mm with a CMM in vertical and horizontal directions. The average absolute offset of the integral field center was measured to be 0.011 and 0.020 mm in vertical and horizontal directions. The average absolute value of the magnet tilt is 0.01° and 0.02° were obtained in CMM and RCS, respectively. The measured integral fields of short-QM, long-QM and sextupole magnets are larger than the nominal field by approximately 2.7 %, 1.4 % and 1.3 %, respectively. The maximum deviations of the integral field of the quadrupole and sextupole magnets are 0.5 % and 0.3 %, respectively. A high-current examination demonstrated that these magnets can be operated at 3 and 3.5 GeV simultaneously.

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