MEASUREMENT OF ACCELERATOR LATTICE MAGNET PROTOTYPES FOR TPS STORAGE RING

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Abstract

Taiwan Photon Source (TPS) is a new third-generation synchrotron storage ring with energy 3 GeV and consists of 24 double-bend cells; its circumference is 518.4 m. Various accelerator lattice magnets consist of 48 bending magnets, 240 quadrupole and 168 multifunction sextupole magnets. All magnet pole profiles, edge shims and magnet end chamfer were designed with TOSCA and RADIA codes for magnetic computation. To verify the quality of the magnetic field from the computation code, prototype magnets have been manufactured. Two measurement systems -- a Hall probe and rotating coils -- served to map the magnetic field. This paper presents the results of mapping the fields of TPS prototype magnets together with original designs of magnetic circuits.

INTRODUCTION

The construction of prototype magnets of 1/24 section has been completed at a local Taiwan company. These magnets include one dipole magnet, two quadrupole magnets with separate yoke lengths and three sextupole magnets with varied shape of iron lamination. The material used for all magnetic core is silicon-steel sheet (thickness 1 mm, No. 50CS1300). The magnet core with electrical insulation and surface treated against corrosion are provided on a special order from China Steel Corporation. A Hall-probe measurement system was used to measure the distribution of magnetic field strength and effective length. A rotating coil was used to measure multipole errors.

MEASUREMENT SYSTEM

The Hall-probe measurement system has two benches of distinct dimension. For measurement of the magnetic field of the dipole and long quadrupole magnets the bench dimension is 200 x 60 x 40 cm^3; for measurement of the magnetic field of the short quadrupole and sextupole magnets the bench dimension is 60 x 20 x 20 cm^3. Each system conducted a modified commercial Hall transducer (SENIS, YM12-5-2T-PT100) with PT100 for temperature record. The transducer output voltage is read with a digital multimeter (Agilent/HP 3458A); the PT100 output signal is read with a multimeter (Keithley/2182).

The method of analysis of Hall-probe measurements has 1D and 2D measures. The 1D measure gives the vertical field $B_y(x)$ and the integral of vertical field $\int B_y(x)ds$ at the mid-plane, expressed with polynomial expansions as

$$B_x(x)+i\,B_y(x)=\sum_{n=0}(a_n/n!)x^n+i\sum_{n=0}(b_n/n!)\,x^n \tag{1}$$

$$\int B_x(x)ds+i\int B_y(x)ds=\sum_{n=0}(A_n/n!)x^n+i\sum_{n=0}(B_n/n!)\,x^n \tag{2}$$

The 2D measure gives the vertical field $B_y(x,y)$ and the integral of vertical field $\int B_y(x,y)ds$ at the circular plane, expressed with polynomial expansions as [1]

$$B_x(x,y)+iB_y(x,y)=\sum_{n=0}(a_n+ib_n)(x+iy)^n \tag{3}$$

$$\int B_x(x,y)ds+i\int B_y(x,y)ds=\sum_{n=0}(A_n+iB_n)(x+iy)^n \tag{4}$$

in which a_n and b_n denote the skew and normal components, respectively. Normalization of the integral field at the region x of effective field is defined as $B_n/B_j=(B_n/B_j)x^{(n-j)}$, in which j is the main component of each magnet and A_n and B_n are the integral skew and normal components, respectively.

A rotating-coil measurement system (RCS) was developed to characterize the quality of the fields of the quadrupole and sextupole magnets [2]. The bench of RCS was assembled on a granite bench. The printed-circuit coil was designed to maintain its position precisely.

RCS is a reliable method for accurate measurement that is used to improve the quality of QM and SM. The qualities of both QM and SM are analyzed with the fast Fourier transform (FFT) method, which was employed to analyze the multipoles of the magnet. To channel the multipoles of the magnet, satisfactory reproducibility of the position is required when the measurement unit and magnet are reinstalled.

DIPOLE MAGNET

The dipole magnet is of H-type, with parallel ends and with the yoke laminations stacked in parallel according to the nominal bending radius. The full gap of the magnet is 46 mm, with a bending angle 7.5° and radius 1.1 m. An end chamfer of dimension 5 mm was applied at the end caps, applying a 45° cut to the pole tip to prove effective in suppressing the sextupole components. Figure 1 shows the cross section of a prototype dipole magnet.

The magnetic field was measured with a Hall-probe measurement system. The field mapping was performed in the midplane along the radial direction at the center of the magnet. The range of data fitting in the horizontal axis is ±30 mm, and the normalized range is ±25 mm. The normalized harmonics of the measured result are near the calculated value, but the dipole field measured is smaller than that calculated at the edge side. Figure 2 shows the distribution of dipole field strength along the longitudinal axis.

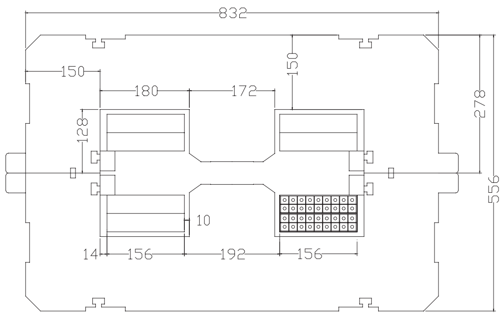

Figure 1: Cross section of a prototype dipole magnet.

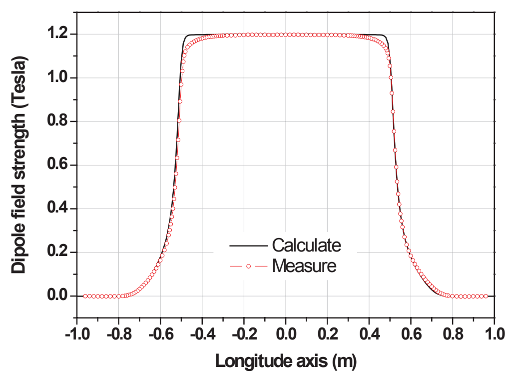

Figure 2: Distribution of field strength along the longitudinal axis

QUADRUPOLE MAGNET

Five families of quadrupole magnet with two magnetic lengths 0.3 m and 0.6 m were measured. The bore radius of all quadrupole magnets is 37 mm, determined by the vacuum chamber and the dynamic aperture of the electron beam. The gradient field strength of the short quadrupole magnet is 17 T/m and of the long quadrupole magnet is 15.63 T/m. To the end caps was applied a 60° cut, the chamfer depth increasing to 14 mm and 12 mm up to the pole tip for the short and long quadrupole magnets, respectively. Figure 3 shows the cross section of a prototype quadrupole magnet.

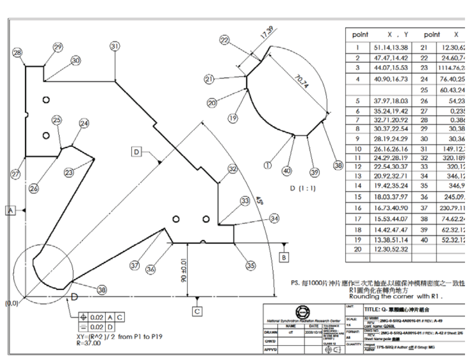

Figure 3: Cross section of a prototype quadrupole magnet

The magnetic field was measured with Hall-probe and rotating-coil measurement systems. Mapping of the magnetic field with a Hall probe was performed in the circular plane along the longitudinal axis. The circular radius is 28 mm and range of data fitting is ±28 mm; the normalized range is ±25 mm. Comparing Hall-probe and rotating-coil measurements, all harmonics are near, but larger than, calculated values. The gradient field of measure is smaller than that calculated at the edge. Figure 4 shows the distribution of field strengths of the short and long quadrupole magnets along the longitudinal axis.

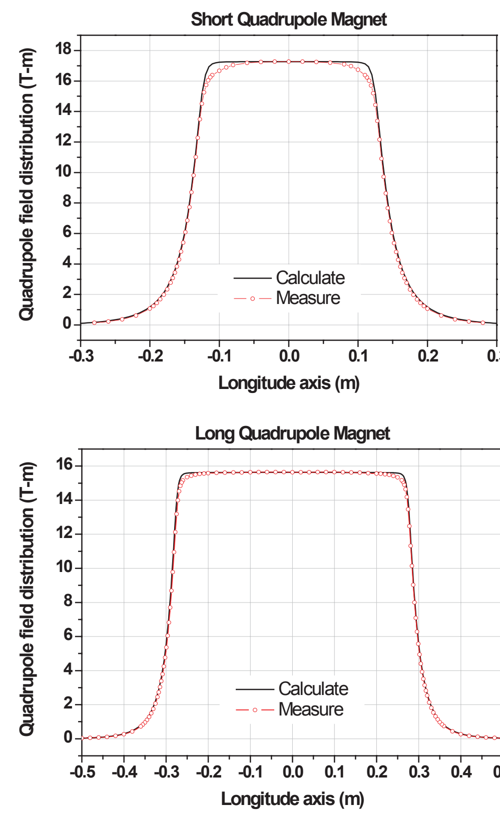

Figure 4: Distribution of field strength of short and long quadrupole magnets along the longitudinal axis.

SEXTUPOLE MAGNET

The sextupole magnet is designed not only for the main sextupole field but also for multipole-field correction of the vertical and horizontal dipoles and the skew quadrupole. The magnets have lamination of three types - SA, SB and SC - with the same magnetic lengths 0.25 m but with separate shapes of iron lamination. The bore radius 39 mm was decided based on the requirements of the field quality and the space constraint between the vacuum chamber and the pole contour; the pole contour R is 39.1 mm so that it can decrease the 30-pole strength. The sextupole magnet gradient is 478 T/m^2 with end caps applying a 45° cut of depth increasing to 6 mm up to the pole tip. Figure 5 shows the cross section of a prototype sextupole magnet (SA, SB,SC).

The magnetic field was measured with Hall-probe and rotating-coil measurement systems. Mapping of the magnetic field of the Hall probe was performed in the circular plane along the longitudinal axis. The circular radius is 28 mm and data fitting range is ±28 mm; the normalized range is ±25 mm. Comparing Hall-probe and rotating-coil measurements, all harmonics are near, but exceed, the calculated values. The measured gradient field is smaller than that calculated at the edge side. Figure 6 shows the distribution of field strength of the sextupole magnet along the longitudinal axis.

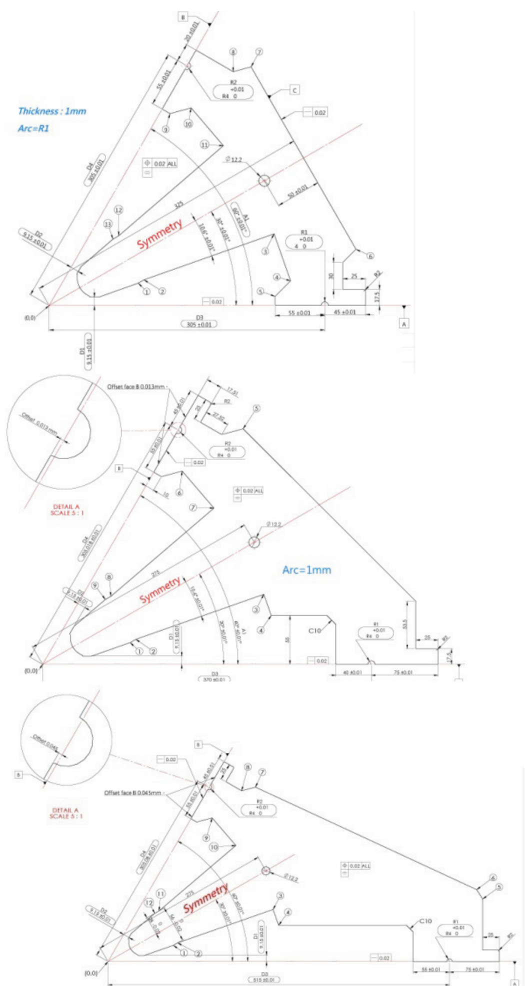

Figure 5: Cross section of a prototype SA, SB and SC magnet

CONCLUSION

The results of the magnetic field with Hall-probe and rotating-coil measurement systems are near.

Form the result of field measurement of the prototype magnets, the field strength and the value of end chamfer are near the calculated values. The multipole errors are greater than calculated because assembly accuracy is inadequate; this work will be improved in the future.

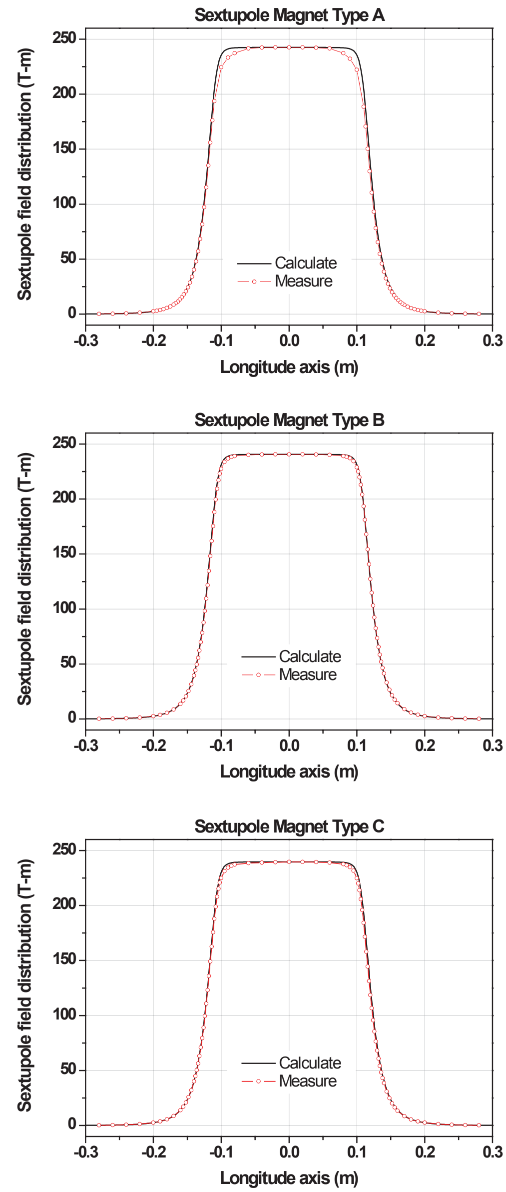

Figure 6: Distribution of SA, SB and SC field strengths along the longitudinal axis

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[2] J. C. Jan, *et al.*, "Design of a Precise unit for the rotating coil"PAC'07, May2007.