MAGNET FIELD CROSSTALK EFFECT OF TPS STORAGE RING MAGNETS

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Abstract

The free space between magnets of Taiwan Photon Source (TPS) storage ring is slight, especially the space between the quadrupole and sextupole magnets. The minimum space between the yokes of quadrupole and sextupole magnets is about 150 mm, but the space between coils is only 10 mm. Accordingly, significant distortions of the magnetic field can have an impact on the performance of the machine. A comparison between two magnets and an individual magnet was simulated with TOSCA 3D. The crosstalk effect shows that the sextupole component normalized to the quadrupole field at x=0.03 m increases from 4×10^{-6} to 4×10^{-3} in the quadrupole magnet and the quadrupole component increases from 8×10^{-6} to 6×10^{-3} in the sextupole magnet. We discuss this crosstalk effect and how to decrease the effect with appropriate shielding.

INTRODUCTION

The TPS will be a highly brilliant synchrotron x-ray source for multidisciplinary experimental research in Taiwan. The most visible feature of the complex will be a 3~3.3GeV electron-storage ring having circumference 518 m. The TPS storage ring consists of approximately 460 magnetic elements, including 48 dipoles, 240 quadrupoles, 168 sextupoles etc [1]. The main parameters of the magnet design are listed in Table 1. Various of these magnets will be placed with an axial spacing between them smaller than in any other machine. The interference harmonics due to the proximity of magnets should be accurately known for ease of commissioning and reliable performance of the machine.

CROSSTALK EFFECT BETWEEN QUADRUPOLE AND SEXTUPOLE

The minimum distance between the yokes of quadrupole and sextupole magnets is about 150 mm, shown in Fig. 1. The beam is along the z-axis and the cross section of the magnet is in the *xy* plane. To compare the quadrupole gradient field (B_1) with and without the sextupole, from a simulation we plot the vertical component of the field (B_y) as a function of z at x=40 mm and y=0 in three cases in Fig. 2. The red line results from only the quadrupole magnet in the space in the calculation of the field distribution; the green line is only from the sextupole magnet in the space, whereas the black line shows the two magnets in the space and both magnets powered. The field decreases to zero at z=236 mm between the two magnets, and the two magnets were separated by this point in this discussion.

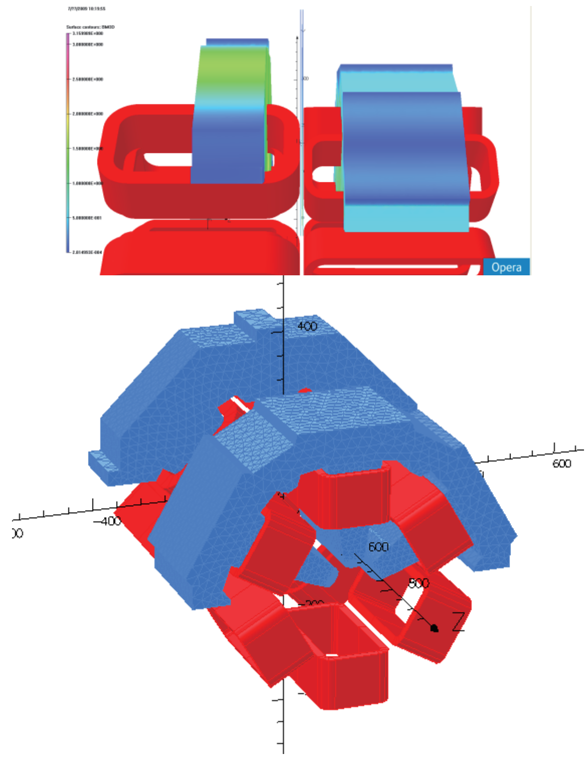

Figure 1: One tight case of the TPS quadrupole and sextupole magnets for study of the crosstalk effect.

Table 1: Specifications of Storage-Ring Magnets

Type	Dipole	Quadrupole	Sextupole
Quantity	48	192/48	168
Length (m)	1.1	0.3/0.6	0.25
Field strength(T,T/m,T/m^2)	1.191	17/15.63	478
Full gap (mm)	46	74	78
Good field region (mm)	40×30	±30	±32
Turns/pole	36	54/48	26
Conductor(mm^2)	16×16	8×8/9×9	8×8
Coolant diameter (mm)	7	4/4.5	4
Current (A)	640	188/187	135
Power/magnet (kW)	8.53	2.56/2.86	0.77
Water circuit number	4	4	2
Water velocity (m/s)	1.23	1.2/1.34	0.73

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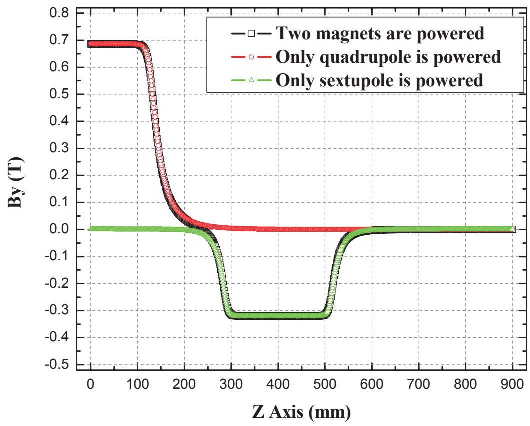

Figure 2: Distance between centers of quadrupole and sextupole magnets is 400 mm. The vertical field component (B_y) lies along the beam axis (x=40mm, y=0) in three cases.

Table 2 shows three cases of field distribution. The fields are all measured along the beam axis at z=0 to 236 mm and x=-40 … 40 mm. For the field data we use polynomial expansions for x=-40 … 40 mm, normalized at x=30 mm. Case 1 is a calculation of only the quadrupole magnet in the space, case 2 has quadrupole and sextupole magnets in the space but only the quadrupole magnet is powered. It shows that the iron of the sextupole magnet provides a shunt path to the fringe field of the quadrupole and decreases its local gradient [2][3] because, according to case 1, the integral field strength ($\int B_1\, dz$) of the quadrupole magnet is larger than for case 2. Case 3 has both magnets in the space, each powered. Through the crosstalk effect the sextupole component increases from 4×10^{-6} to 4×10^{-3} in the quadrupole magnet and in case 3 the integral field homogeneity becomes worse than the others in Fig. 3.

Table 2: Three situations in the region of the quadrupole magnet. The field is normalized to quadrupole at x=30 mm.

Z=0~236	**case 1** **Only the quadrupole magnet is in the space.**	**case 2** **Only the quadrupole magnet is powered.**	**case 3** **Both magnets are powered.**
$\int B_0$ dz / T m	1.83×10^{-6}	-3.9×10^{-6}	-1.4×10^{-4}
$\int B_1$ dz / T	5.11	5.10	5.10
$\int B_2$ dz / T m^{-1}	4.8×10^{-3}	1.4×10^{-3}	-1.28
NB_0	1.2×10^{-5}	-2.5×10^{-7}	-9×10^{-4}
NB_1	1	1	1
NB_2	1.4×10^{-5}	4.1×10^{-6}	3.8×10^{-3}

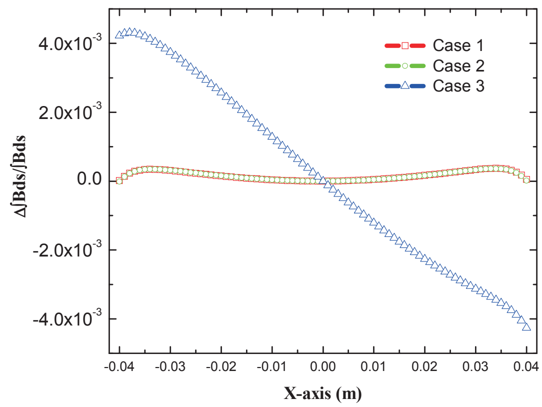

Figure 3: Field homogeneity of the integral fields on the transverse x-axis; $\Delta\int Bds/\int Bds = [\int B(x)\, ds-(B_0+ B_1x)]/\int B(x)\, ds$.

The cases for the sextupole magnet are similar to those for the quadrupole magnet. The fields are all measured along the beam axis at z=236 … 900 mm and normalized at x=32mm. The crosstalk effect shows that the quadrupole field component increases from 8×10^{-6} to 6×10^{-3} in the region of the sextupole magnet.

Table 3: Three situations in the region of the sextupole magnet. The field is normalized to sextupole at x=32 mm.

Z=236~900	**case 4** **Only the sextupole magnet is in the space.**	**case 5** **Only the sextupole magnet is powered.**	**case 6** **Both magnets are powered.**
$\int B_0$ dz / T m	5.6×10^{-6}	3.0×10^{-5}	3.0×10^{-5}
$\int B_1$ dz / T	-7.7×10^{-6}	1.2×10^{-5}	9.8×10^{-3}
$\int B_2$ dz / T m^{-1}	100.9	100.9	100.9
NB_0	1.1×10^{-4}	5.8×10^{-4}	5.8×10^{-4}
NB_1	-4.8×10^{-6}	7.6×10^{-6}	-6×10^{-3}
NB_2	1	1	1

SHIELDING EFFECT

For optimum performance of the TPS storage-ring magnets, the crosstalk between quadrupole and sextupole magnets in TPS should be decreased by shielding. The size of the vacuum chamber of the TPS storage ring is 106 mmx38 mm; the cut size of the steel shield must be larger than the size of the vacuum chamber. Figure 4 shows four cut shapes of steel shield to separate quadrupole and sextupole magnets, both of thickness 5 mm, and the shield material is chosen as silicon steel. Table 4 presents the magnetic-shielding performance of four shapes. Shape 1 shield is evidently the best result to decrease crosstalk effects. The size of the steel cut to fit the chamber size is the ideal shield shape.

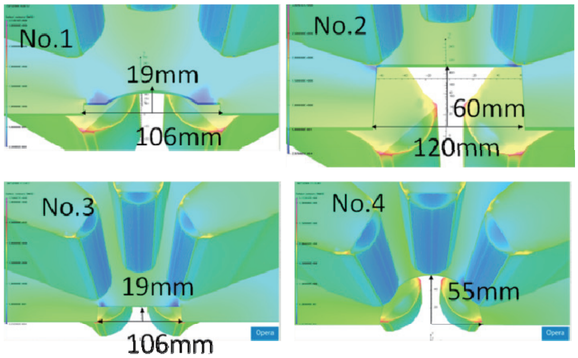

Figure 4: Four shapes of steel shield.

Table 4: Performances of Four Shapes of Shield Compared to No Shielding

Region	***Z*=0~236**		***Z*=236~900**	
	NB_0	NB_2	NB_0	NB_1
No shield	-9.0×10^{-4}	-3.8×10^{-3}	5.8×10^{-4}	-6.0×10^{-3}
No.1	-2.0×10^{-4}	$\underline{-1.8\times10^{-3}}$	5.5×10^{-5}	$\underline{-1.1\times10^{-4}}$
No.2	-2.9×10^{-4}	-2.3×10^{-3}	9.8×10^{-5}	-7.8×10^{-4}
No.3	-1.9×10^{-4}	-1.9×10^{-3}	5.7×10^{-5}	-1.4×10^{-4}
No.4	-1.8×10^{-4}	-2.2×10^{-3}	5.3×10^{-5}	-3.7×10^{-4}

The minimum distance between the quadrupole and sextupole magnet coils is 10 mm; a steel shield can fit in the space with thickness less than 10 mm. Varied thicknesses of No.1 shape steel shield are shown in Fig. 5. The distance of steel shields are 1 mm and 2 mm for the TOSCA 3D simulation. Table 5 shows the results of thickness (t) and distance (d) of shielding effects; a large space between two pieces of steel has the best effect to shield from crosstalk fields. The quadrupole component (NB_1) is decreased from 1.1×10^{-4} to 9.4×10^{-5} by two pieces of steel.

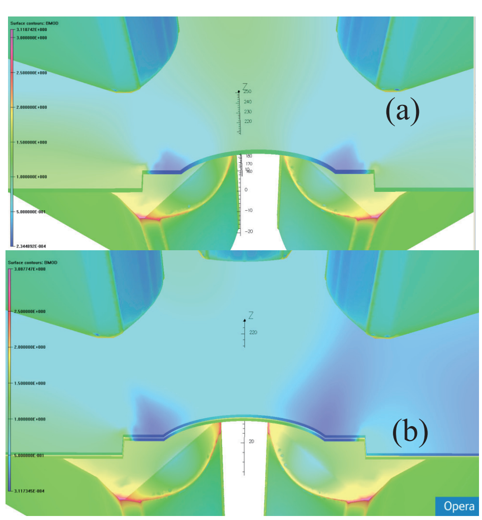

Figure 5: Varied thickness of No.1 steel shield, (a) one shield of 5 mm (b) two shields of thickness 2.5 mm separated 1 mm.

Table 5: Varied thickness (t) and distance (d) of No.1 steel shield, two shields of thickness 2.5 mm separated 2 mm, which yields the best result.

Region	***Z*=0~236**		***Z*=236~900**	
No.1 shielding	NB_0	NB_2	NB_0	NB_1
t=5 mm	-2.0×10^{-4}	-1.8×10^{-3}	5.5×10^{-5}	-1.1×10^{-4}
t=2.5 mm d=1 mm	-1.1×10^{-4}	-1.7×10^{-3}	4.3×10^{-5}	-1.0×10^{-4}
t=2.5 mm d=2 mm	-1.0×10^{-4}	-1.7×10^{-3}	3.5×10^{-5}	$\underline{-9.4\times10^{-5}}$

CONCLUSIONS

This paper reports the crosstalk effect and the shielding effect of TPS quadrupole and sextupole magnets. Because of the crosstalk effect, the sextupole component increases 3 order in a quadrupole magnet and the integral magnetic field homogeneity becomes worse. The quadrupole component also increases 3 order in a sextupole magnet. The optimised cut shape for magnetic shielding is the one with tightly fit with vacuum chamber. The quadrupole component decreases 2 order when two pieces of steel use between magnets. In the future, we shall perform the simulation with various geometries and materials for the shielding mechanism. This work will help us on TPS storage ring commissioning.

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