DESIGN AND PERFORMANCE OF VARIOUS KINDS OF CORRECTOR MAGNETS FOR THE TAIWAN PHOTON SOURCE

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Abstract

DC corrector magnets of three types will be installed in the booster ring (BR), LINAC to booster (LTB) and booster to storage ring (BTS) in the Taiwan photon source (TPS). These DC corrector magnets have different gap size, iron length and field strength to match the vacuum chamber dimension. The DC magnetic fields were simulated with static field analysis (Opera 2D/3D); optimum processes are discussed. An AC steering rapid feedback corrector (FFC) combines horizontal and vertical dipole fields for rapid feedback correction in the storage ring (SR). The variation of field with alternating current (frequency 300 Hz) of the FFC magnet is simulated with an analysis module (Opera 3d ELEKTRA /SS) to estimate the operating current. This paper discusses the features, the design concept and the results of field measurements of these corrector magnets.

INTRODUCTION

The Taiwan photon source is a third-generation accelerator for a light source designed to achieve great brilliance and small emittance [1]. Corrector magnets required for the operation of TPS are horizontal corrector, vertical corrector and AC corrector. To simplify the functions of correctors for various vacuum chamber dimensions, there are DC corrector magnets of just three kinds, and an AC corrector of one kind. The pole gap of the DC corrector magnets (types A and B) is 40 mm, but 71 mm for type C. The iron length of corrector magnets (types A and C) is 100 mm, but 170 mm for type B. The booster ring contains 60 horizontal and 36 vertical corrector magnets (type A), the BTS contains seven (type A) and four (type B) corrector magnets; the LTB contains 12 corrector magnets (type C). The rapid feedback corrector will be installed between a dipole magnet and a quadrupole magnet in the storage ring. Because of the limited space, a maximum overall length 70 mm is allowed for a combined horizontal and vertical correction FFC magnet [2]. The design of the FFC magnet requires optimization because of its atypical shape; its construction is described. To fit the size of the vacuum bellows, the pole gap of the FFC is 84 mm and the pole width is 124 mm. The specifications of the DC corrector and FFC magnets are listed in tables 1 and 2. In this paper we present the design of the iron yoke and the coil parameters, and the results of field measurements.

DC CORRECTOR DESIGN

The yoke of DC correctors has a C shape that makes easy the installation of the magnet. This C-shape magnet is one piece so to avoid error of assembly. The advantage of this design is the ease of control of the quality of the magnetic field. The iron yoke is laminated with silicon steel (1 mm) and wire cutting of the pole tip. The dimensions of the copper of the corrector are 2 mm x 3 mm, with cooling by air. The coil turns number 96 per pole for types A and B correctors, but 160 for type C. The shape of the DC corrector magnet is shown in figure 1; the location and function are listed in table 3. A magnet of each type is usable as a vertical or horizontal corrector; we discuss below horizontal correctors with vertical fields. Regarding the asymmetric properties of the magnet of C shape, the pole-tip shims can be designed with varied sizes of both sides to make the field homogeneity symmetric as in figure 2. The region of good field (GFR) is ±15 mm horizontally for types A and B, and ±20 mm for type C. The final design result for the field quality of the central field is within 0.1 %, shown in figure 3. The integral field homogeneities are within 1 % without the end shim blocks of the pole. Adding end shims to the pole tips can improve homogeneities to 0.02 %.

Table 1: Parameters of DC Corrector Magnets

Parameters	Unit	Type A	Type B	Type C
Iron length	m	0.100	0.170	0.100
Magnet length	m	0.138	0.209	0.158
Normal field	T	0.050	0.050	0.036
Bending angle	mrad	0.690	1.045	11.376
Magnet gap	m	0.040	0.040	0.071
Pole width	m	0.090	0.090	0.120
Conductor dimension	mm	3×2	3×2	3×2
Number of turns/pole		96	96	160
Current	A	8.479	8.479	6.528
Resistance	Ω	0.310	0.390	0.562
Power consumption	kW	0.022	0.028	0.024
Inductance (OPERA)	mH	20.1	30.4	54.4
Voltage drop	V	2.631	3.303	3.669
Mass of conductor	kg	9	12	17
Mass of iron	kg	28	48	38

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Table 2: Parameters of FFC Corrector Magnets

Parameters	**Unit**	**HC**	**VC**
Magnet quantity		100	100
Iron length	mm	30	30
Magnet gap	mm	84	84
Conductor dimension	mm	3×2	3×2
Normal field	Gauss	94	40
Number of turns/pole		40	40
Current	A	10	10
Operating frequency	Hz	300	300
Coil length	m	39	38
Resistance	Ω	0.08	0.07
$\Delta B/B$ X=-25...25mm Y=-10...10mm	%	1.2	2.2
Inductance	mH	1.27	0.946
Average power	W	84.8	63.2
Voltage max	V	22.0	16.5

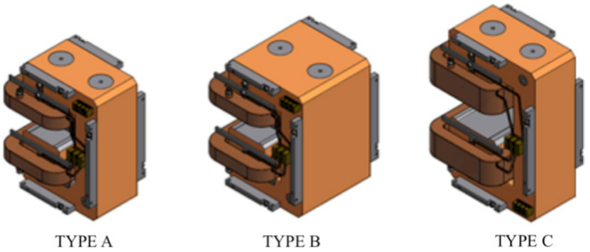
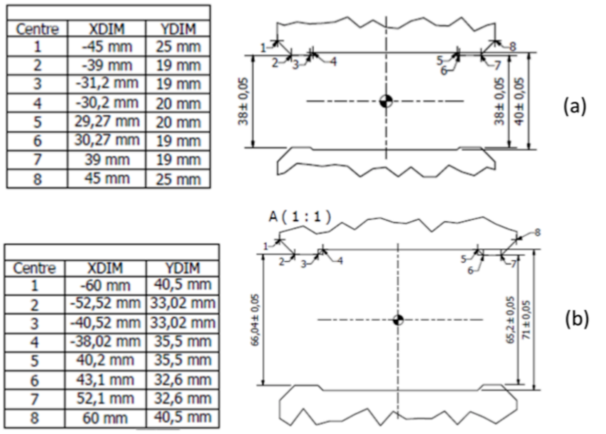


Figure 1: Drawing of DC corrector magnets. Types A and B have the same cross section but different lengths; type C has a bigger gap and a higher iron yoke.



Centre	XDIM	YDIM
1	-45 mm	25 mm
2	-39 mm	19 mm
3	-31,2 mm	19 mm
4	-30,2 mm	20 mm
5	29,27 mm	20 mm
6	30,27 mm	19 mm
7	39 mm	19 mm
8	45 mm	25 mm

Centre	XDIM	YDIM
1	-60 mm	40,5 mm
2	-52,52 mm	33,02 mm
3	-40,52 mm	33,02 mm
4	-38,02 mm	35,5 mm
5	40,2 mm	35,5 mm
6	43,1 mm	32,6 mm
7	52,1 mm	32,6 mm
8	60 mm	40,5 mm

Figure 2: (a): Pole profiles of types A, B (b): profile of type C. The open side of the C shape iron yoke is at the right, the left side is a closed loop.

Table 3: Locations and Functions of Correctors

Parameters	**BR**		**LTB**		**BTS**		
Quantity	60	36	5	7	5	2	4
Function	HC	VC	HC	VC	HC	VC	VC
Type	A	A	C	C	A	A	B
Normal field /G	500	360	360	360	500	500	500

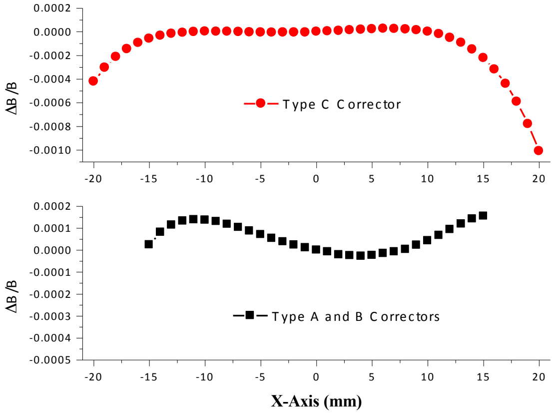


Figure 3: Homogeneity of central field of DC correctors

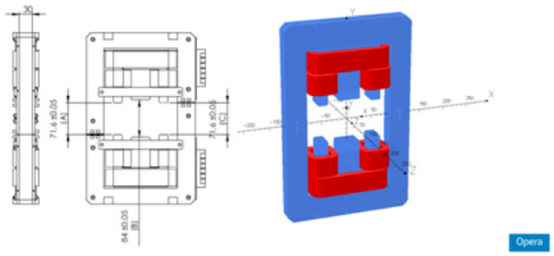


Figure 4: Engineering design and OPERA 3D view of a FFC magnet.

FAST FEEDBACK CORRECTOR DESIGN

The FFC is located between the dipole and quadrupole magnets. The space allowed in the longitudinal direction is only 100 mm, which must accommodate also a bellows of the vacuum chamber. The height of the bellows is 48 mm; the width is 88 mm. The fast feedback algorithm requires a bending angle 340 μrad for correction beside these space-limited conditions. The system to cool the FFC coils is air cooling; two direction fields must also consider the field strengths, so an air coil corrector is not viable: because of large gaps for vertical and horizontal directions, an air coil corrector requires many ampere turns to attain the target field strength. The coil of the air coil corrector exceeds the size in the longitudinal direction. The chosen FFC has a laminated steel return yoke; even though loss through hysteresis and eddy currents affects the field strength, this way achieves a desired field strength within a limited space. The shape of the FFC magnet is shown in figure 4. The field homogeneities in both directions are allowed within 1 %. The field strength and field homogeneity varies with increasing operating frequency, as indicated in table 4.

Table 4: Variation of Field Strength and Homogeneity of FFC with Frequency by Simulation

Fast Feedback Corrector at 10 A								
Correction direction	Vertical field				Horizontal field			
Region of good field	*X*=±25 mm				*Y*=±10 mm			
Frequency /Hz	0	100	200	300	0	100	200	300
Field strength /G	94	85	72	61	39	39	40	40
Central field $\Delta B/B$ /10^{-3}	3	4	5	7	2	2	2	2

EXPERIMENTAL RESULTS

DC Corrector Magnet

The DC correctors were tested at nominal currents (A/B=8.5 A and C= 6.5 A) with a Hall probe system (by Danfysik, manufacturer of DC corrector and AC FFC magnets). The results of measurements appear in table 5. The field strength, central field homogeneity ($\Delta B/B$) and integral field homogeneity (dI/I) are all within the specifications. These experimental results match the simulation results. The effective lengths of these magnets are all greater than specifications; the reasons might be differences of *B-H* curves between ideal and actual, or the fringe fields of coils are larger than in the simulations.

Table 5: Results of Field Measurements, DC Correctors

G.F.R: ±15mm	**Spec.**	**A**	**B**	**C**
$\Delta B/B$ /10^{-3}	1	0.51	0.82	1.1
B /T	0.05@8.5A 0.036@6.5A	0.05	0.05	0.036
dI/I /10^{-2}	1	-0.44~ 0.21	-0.27 ~ 0.13	0.29 ~ 0.23
Effective length /m	0.138 (A) 0.209 (B) 0.158 (C)	0.143	0.212	0.162

Fast Feedback Corrector Magnet

Measuring the FFC magnet with a Hall probe or search coil yields almost the same results. Power supply system provides 10 A as normal full sine waveform up to frequency 140 Hz, above which the waveform changes to a triangular shape. The vertical field strength deteriorates for frequency greater than 140 Hz. *B-I* curves for varied frequency appear in figure 5. The harmonic error results are measured with a circular vertical field for the HC and a circular horizontal field for the VC. The integral harmonic errors are shown in figure 6.

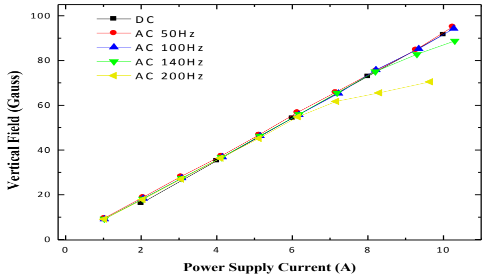


Figure 5: Variation of B-I curves with frequency

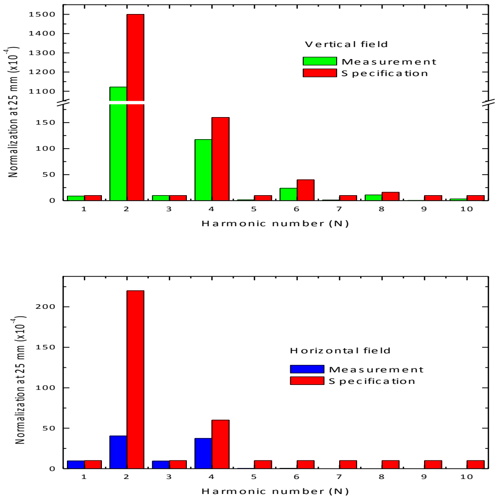


Figure 6: Harmonic measurements compared to specifications

CONCLUSION

The designs and results of measurements are presented in this paper. DC corrector and FFC magnet experimental results achieved the design specifications. The power supply for the FFC will be modified for future retesting.

REFERENCES

[1] C. C. Kuo et al., "Design of Taiwan Future Synchrotron Light Source", Proceedings of the EPAC'06, June 2006, p. 3445 (2006).

[2] G. Danby et al., "Design and Measurement of the NSLS-II Correctors", Proceedings of PAC09, Vancouver, BC, Canada, pp.148-150 (2009).