THE MAGNETIC PERFORMANCE OF TWO UNDULATORS FOR HLS

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Abstract

An elliptically polarized undulator and an in vacuum undulator for HLS have been built at SSRF. The magnetic design of the two Undulators is reviewed. Measurements of the complete undulators are described. Results of performance optimization, including minimization of optical phase error, trajectory wander and integrated multipoles with magic fingers are presented.

INTRODUCTION

SSRF has made a large improvement in undulator technology in the past few years, providing end users with high performance in-vacuum devices and elliptically polarizing undulators as well as regular planar devices for FEL applications. As the undulators demand for HLS reconstruct program developed, we were keen to accept this challenge to build one EPU and one IVU. The specifications of the two undulators are list in Table 1.

Table 1: Magnetic Specifications

	EPU104	IVU40
Period Length (mm)	104 mm	40 mm
Number of Periods	30	30
Magnetic Structure	APPLE-II ,PPM	Hybrid
Max. Peak Field (T)	>0.34 >0.65	>1.01
Gap range (mm)	30-80	10-30
R.M.S. Phase Error	<5°	<3°
FirstIntegral Fields (G.cm) @ x =0	<100	
Second Integral Fields (G.cm^2) @ x =0	<20000	
Multipoles @ x =0	Quadupole (G)<100 Sextupole (G/cm)<150 Octupoles (G/cm2)<200	

The EPU has 30 periods with period length 104 mm corresponds to four standard Halbach-type magnet arrays which consist of two pairs of planar permanent magnet arrays above and below the electron orbit plane. The two arrays at one diagonal can move in 52 mm along the longitudinal direction to provide various elliptical polarization modes. The IVU structure is a SPring-8 type with two parallel arrays of permanent magnets (PM) and high-permeability poles mounted within the ultra-high vacuum (UHV) of the storage ring. The total length of the IVU is about 1.2 meter with period length 40 mm. We have recently successfully completed. The magnetic and mechanical designs were finished by SSRF on August 2012. All the magnet blocks used in the two undulators were supplied by Chinese magnet manufacturers. The magnetic measurement and magnetic field shimming were finished in February at SSRF measurement laboratory.

MAGNETIC DESIGN

The magnetic fields for EPU104 were calculated by RADIA[1] using the analysis formulae for each magnet and then linearly superposed for all the magnets. The blocks are chosen 32×32mm section with two cuts 4 ×4 mm designed for mounting. The remanence of the NdFeB magnet with grade N38SH is supposed to be 1.25T. The magnet holder can be adjusted within ±0.25mm in horizontal and ±0.5mm in vertical positions. The clearance of 2.8mm between two magnet arrays provides the space for the magnet holder adjustment in horizontal direction. At the minimum gap 30mm, the magnetic field can reach 0.65T in horizontal polarization, 0.43T in vertical polarization and 0.36T in circular polarization, see Fig. 1.

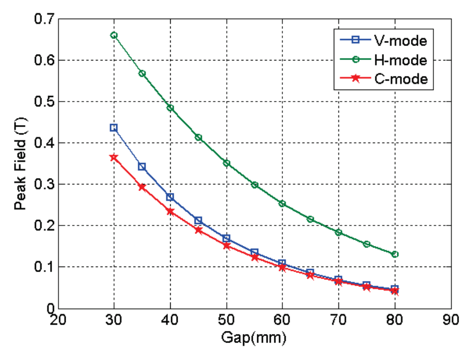

Figure 1: Peak field of three polarizations vs. gaps.

We optimized the end design such that the field integral variation at various polarizations was minimized at gap 30mm, see Fig. 2. The optimized sizes of end blocks were 6.5mm, 6.5mm and 19.5mm (from end to centre) with a 16mm space, the first and second field integral for different shift at gap 30 mm are shown in Fig. 3.

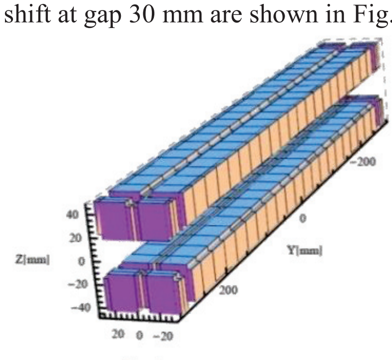

Figure 2: Layout of EPU104 5 periods model.

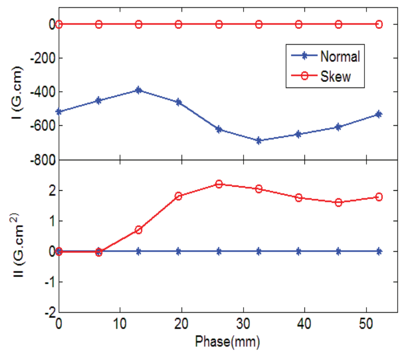

Figure 3: The extrapolated field integral vs. phase at gap 30mm.

The magnetic performance of IVU40 was calculated with the Vector-fields OPERA [2]. To achieve the required field of 1.01 T at 10 mm gap, the optimized sizes of magnet blocks are 74mm (wide), 40 mm (height) and 14.4 mm (thickness). There is a 4 mm deep, 45° cut at the corners to clamp the blocks in the holders. The blocks are made from Sm2Co17 with a minimum remanence of 1.12 T and must be coated with TiN or Ni to be HUV compatible. We designed a 2 x 2 mm chamfer on the magnet blocks to eliminate demagnetization nearest to the neighbouring pole. The poles with a low carbon material are 5.6 mm thick, 31 mm high and 43 mm wide. A 4 x 4 mm^2 ear is sticking out on each side to secure the pole in the pole holder. There is a 3 mm deep, 45° cut at the pole bottom to increase the flux density in the middle of the pole and improve the transverse roll-off, see Fig. 4.

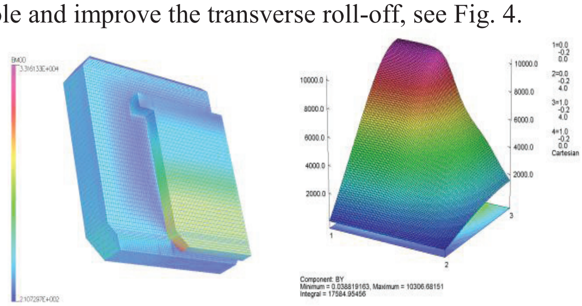

Figure 4: Layout of 1/4 period model and magnetic flux density distribution on the magnetic mid plane.

MEASUREMENT RESULTS

A 3-dimensional Hall probes and flipping coil system is used to measure the magnetic field mapping and the first and second field integrals. All the field correction for both undulators is done at the minimum gap. This is quite natural because the magnetic performance is more sensitive to imperfections of magnets as the gap value decreases.

The phase errors and the electron trajectories of EPU104 were shimmed by adjusting the positions of magnet blocks and minimizing the dispersion of the field integrals over half periods [3]. Figure 5 shows the electron trajectories and phase errors of EPU104 in three linear polarizations after shimming. The average orbit off is less than 20μm in horizontal polarization, less than 50μm in vertical polarization. After shimming the RMS phase error at gap 30mm have be reduced from 9.1, 14.8 and 14.6 to 3.84, 5.74 and 5.76 for different shifts 0, ±52mm. The RMS phase errors for all gaps are less than 4° the phase errors of shifts ±52mm at the measured gaps (30, 40 and 60mm) are below 6°, list in Table 2.

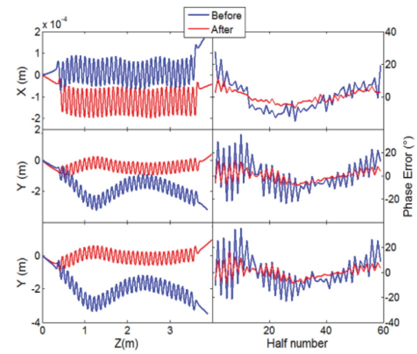

Figure 5: Comparison of on-axis electron trajectories and optical phase errors of EPU104 before (blue) and after (red) shimming. For horizontal polarization shift 0 (top), vertical polarization shift -52mm (middle) and 52mm (bottom) at gap 33 mm.

To meet magnetic specification IVU40 were shimmed by put shims between magnet holder and girders. The effect of the field correction is significant. The electron trajectory at gap 10mm is less than 2μm and the RMS phase error at gap 10mm is be reduced from 9.7° to 1.45°, shown in figure 6. The peak fields and the RMS phase errors for different gaps are list in Table 4, the maximum RMS phase error 2° occurs at the gap 20 mm.

Table 2: The RMS phase errors of EPU104

Gap (mm)	RMS phase errors (Deg.) Shift=52mm	Shift=0	Shift=-52mm
30	5.76	3.84	5.74
35		3.48	
40	6.04	3.2	6
50		3.11	
60	5.25	2.91	5.2
80		2.44	

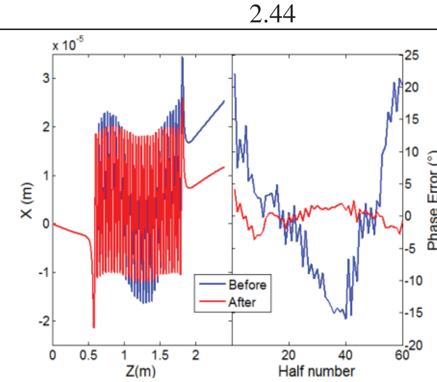

Figure 6: IVU40 Magnetic performances in terms of on-axis electron trajectory (left) and the optical phase error as function of the half period number (right) and before (blue) and after (red) shimming at gap 10 mm.

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Table 3: Magnetic Performances of EPU104 After the Correction for Different Shifts at Gap 30mm. The abbreviations of Di., Quad., Sext. and Octu. denote the dipole, quadruple, sextupole and octupole components expressed in units of G.cm, G, G/cm, andG/cm2. Normal and skew means the vertical and horizontal field, respectively.

Shift (mm)	Normal Component				Skew Component			
	Di.	Quad.	Sex.	Octu.	Di.	Quad.	Sex.	Octu.
-52	-12.3	-54.7	4.3	18.3	33.0	33.8	75.9	-33.1
-34	-6.1	-5.2	5.3	1.8	10.6	33.3	84.5	-33.4
0	-0.7	71.6	-15.7	-30.4	-22.3	28.3	83.3	-33.6
34	0.0	-43.7	-6.4	14.0	21.8	22.0	72.2	-32.3
52	4.7	-42.6	-7.1	14.9	37.4	18.1	68.7	-26.9

Table 4: Phase Errors and Multipoles of IVU40 After the Correction at Various Gap Values

Gap	Peak Field	Phase Error	Normal Component				Skew Component			
(mm)	（T）	(degree)	Di.	Quad.	Sex.	Octu.	Di.	Quad.	Sex.	Octu.
10	1.05	1.49	50.6	34.4	7.3	-48.7	12.2	18.2	77.2	32.1
12	0.86	1.52	-18.8	-2.9	26.3	-31.7	28.2	-13.9	44.3	-11.0
15	0.64	1.82	-38.1	-28.4	10.4	-4.5	36.0	-22.8	21.3	-21.0
20	0.41	2.0	-35.9	-33.4	22.1	19.3	38.4	-24.6	5.9	-23.7
25	0.27	1.98	-18.6	-23.2	14.4	25.4	37.3	-17.6	-4.0	-9.5
30	0.18	1.48	10.4	3.3	29.1	20.8	34.8	11.3	-9.8	-2.4
45	0.06	0.40	37.4	16.5	17.2	11.3	32.7	36.1	-6.0	5.5

After the local field shimming was finished, the first and second field integrals and the multipoles were measured using the flipping coil system. The flipping coils system can collect the signals in each 45 degree angle so both normal and skew field integrals can be measured. The multipoles of the field integrals are corrected by using the "magic fingers" located at the ends of magnet arrays.

It should be pointed out that this kind of "magic fingers" cannot be able to correct any phase-dependent field errors of EPU, since the integrated effect of the "magic fingers" is essentially independent of their longitudinal positions. Fig. 7 and 8 shows the gap dependence of on-axis field integrals of the EPU104 and IVU40. The optimized results of EPU104 are not as good as we expected particularly in the minimum and maximum gaps. At the minimum gap 30mm the multipole component for different phase shifts of EPU104 are within the specifications list in Table 3. The multipoles of IVU40 at the gap values other than 10 mm have been also as good as the specifications, shown in Table 4 in terms of the phase error and total multipoles.

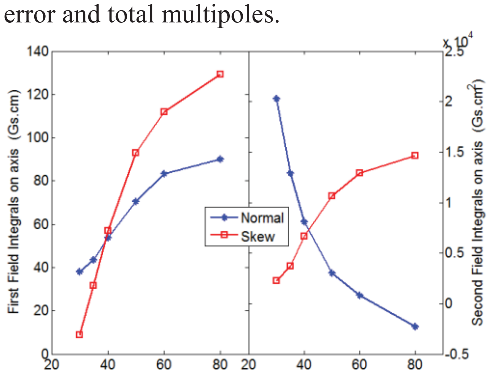

Figure 7: Field integrals of EPU104 as functions of gaps after the correction for both the normal (blue) and skew (red) components.

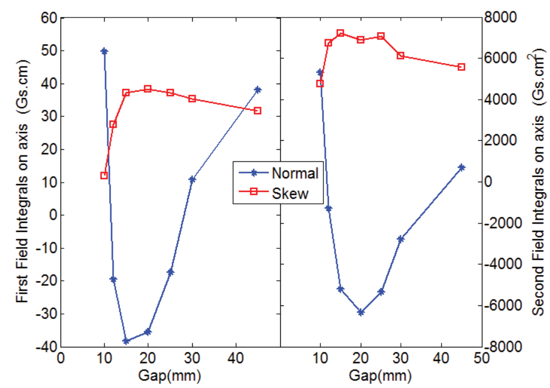

Figure 8: Feld integrals of IVU40 as functions of gaps after the correction. For both the normal (blue) and skew (red) components, the effect of the field correction is significant.

CONCLUSIONS

Magnetic field measurements on the two undulators have been completed at SSRF. The magnetic optimization is successful and showed good performance of both undulators especially for IVU40. Further improvements in magnetic field correction particular in EPU are possible. HLS is under construction now and the undulators will be installed later.

REFERENCES

[1] http://www.esrf.eu/Accelerators/Groups/InsertionDevices/Software/Radia

[2] OPERA-3D/TOSCA. Vector Fields Ltd, Oxford, England.

[3] W. Zhang, J. Lu, Q. Zhou, and H. Wang, Applied Superconductivity, IEEE Transactions on, VOL. 20, NO. 3, JUNE 2010.