INFLUENCE OF MAGNET ERRORS AND WAVEGUIDE PERMEABILITY ON MAGNETIC FIELD PERFORMANCE IN PURE PERMANENT UNDULATORS

Xialing Liu*, Bin Qin, Lei Yang , Yongqian Xiong, Jun Yang, Ping Tan , Kaifeng Liu , Bang Wu
State Key Laboratory of Advanced Electromagnetic Engineering and Technology ,Huazhong University of Science and Technology, Wuhan 430074, Hubei, China

Abstract

For pure permanent magnet (PPM) undulator, unavoidable divergences of remanence field and magnetization vector in PM blocks and installation error will cause magnetic field error at the central line of the undulator. This paper presents the simulation results of the magnetic field in non-ideal undulator containing these errors, with specified tolerances in Normal distribution. As well as the peak field error, increases of the harmonic components and impact on field integrals are calculated. The influence on magnetic field caused by waveguide permeability is also discussed.

INTRODUCTION

PPM undulator is featuring a magnetostatics periodic (sinusoidal) field in the longitudinal (z) direction by the periodic arrangement of the magnet block [1]. There is a significant difference between the actual undulator and ideal electromagnetic model, which includes unavoidable divergences of remanence field and magnetization vector in PM blocks and installation error [1]. The quality of the undulator field was often characterized by its RMS deviation from the ideal model such as peak field error, harmonic components, field integrals and phase error. Generally, a magnetic field with RMS field error is given by a sine-like type with a piecewise constant amplitude varying from each half-period respectively [2, 3].

In this work we have developed a code that generates numerically different types of errors and calculates their effects. With the help of RADIA [4], we 1) tried to establish two rows of permanent magnets with remanence error, magnetization direction error, block width error and assembly position error, 2) study the influence of different types of PM errors on magnetic field errors, 3)set tolerance limits for the specification of the permanent magnet.

Table 1: Undulator Parameters of HUST-FEL

Beam energy	6~12 MeV
Undulator period number	30
Undulator parameter *K*	1.0-1.25
gap_{min}	17.5mm
λ_u	32mm
The permanent magnet block size	
X	75mm
Y	7.9mm
Z	25mm

*ourxialing@qq.com

All calculations were done for the undulator parameters of the FEL proposed by Huazhong Univesity of Science and Technology (HUST-FEL), which are listed in Table 1.

CALCULATION OF MAGNETIC FIELD

The three-dimensional structure of the physical model of PPM undulator is shown in Figure 1. It is classical Halbach structure. The material of PM block is Sm_2O_5 with remanence of 1.14T.

The first and second integrals on axis stand for the angle and offset of deflection of the electron beam orbit that will generate orbit distortion and reduce the radiation intensity [2]. They are calculated numerically using trapezoidal rule with 64 points per period, which provides the necessary accuracy and integration stability. The field integrals requirement of HUST-FEL is 5.0e−6T • m and 2.5e−6T • m^2 [1], it asks for precise design for the end part formation. When the undulator gap is set as 17.5mm, ends optimization results in：I_{1st}=0.736 e−6T • m, I_{2nd}=0.439 e−6 T • m^2,B_m=0.36016 T.

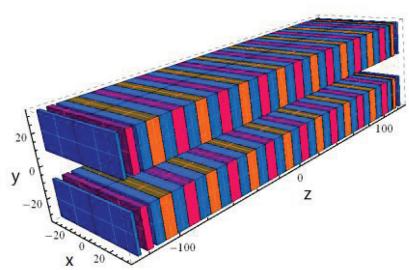

Figure 1: An idealized Shortened HUST-FEL undulator modeled with RADIA.

The radiation phase on the axis is [3]:

$$\varphi(z)=\frac{2\pi}{\lambda}\left[\frac{z}{2\gamma^2}-\int_0^z\frac{\theta^2(z)}{2}dz\right]. \quad (1)$$

Assuming the number of peaks is N_p, establish a linear fit φ_{i0} based on the phase at peaks φ_i calculated by the equation (1) [3]. The actual phase deviation at the peaks is $\delta_i=\varphi_i-\varphi_{i0}$. The RMS error of phase deviation δ_i is known as the measurable phase error σ_φ. The phase error is 0.17° in the no-error model.

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ERROR SIMULATION

Commonly, Kincaid magnetic field error model [3] is widely used because it has a clear analytical formula (2).It means signing the random distribution of errors in each of the positive and negative peaks of the ideal sinusoidal distribution field. It can be easily to obtain the analytical relations of the peak error and phase error, field integrals in this error model. However, this model is different from the real undulator magnetic field containing errors, because it ignores the impact of the end part, and cannot simulate the period length error. What's more, it cannot characterize the impact of the PM block errors on field waveform. This section will obtain the impact of PM block errors on the performance of the magnetic field.

$$B(z) = \overline{B_m}(1+\delta_i)\sin t \quad t_{i-1} \le t \le t_i, t_i = i\pi, i = 1,2,\ldots,N_p \quad . \tag{2}$$

The four main PM block errors are listed in Table 2. At first, A set of m random Br_i -values was generated in Gaussian distribution with standard deviation σ. Br_i is equal to one PM block's remanence. Then the undulator model of heterogeneity parameters was calculated in RADIA. Other three types of magnet block errors was generated in the same method.

Table 2: Four Main Permanent Magnet Block Errors

Source	Errors' Type	Expression
Inhomogeneity of the materials	RMS remanence error	σ_{Br}/Br
	RMS magnetization direction error	$\sigma_{angle}/90°$
PM block cutting error	RMS width error of magnets	σ_z/z
Installation error	RMS gap height error	σ_{gap}/gap

Fig.2 displayed an excellent linearity between the RMS field error σ_{Bm}/B_m and σ_{Br}/Br, $\sigma_{angle}/90°$, σ_{gap}/gap within the ranges of 0.1% -1%. It's found that the error transfer coefficients were 0.62, 0.72, and 0.67 respectively in regression equation. Width error of magnets has the biggest influence on field error and there is not a linearity between them.

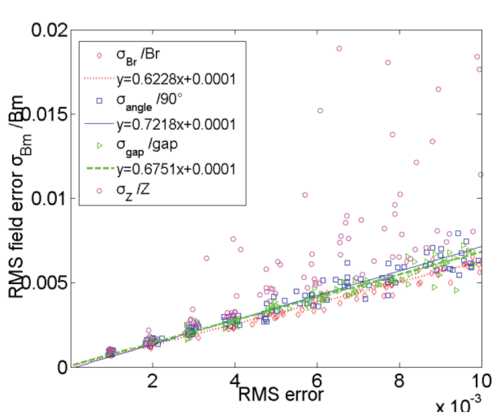

Figure 2: RMS field error at different PM errors. Width errors (Purple circle) have a dramatic effect on field error.

The σ_z/z has the greatest impact on the harmonic since that it disrupts the undulator period for PPM undulator. Even so, the harmonic component of the 2nd , 3rd is less than 0.4%.

Except for the σ_{gap}/gap, the other three PM errors have a dramatic effect both on the first and second integrals which is far more than the target value as shown in Fig.4.

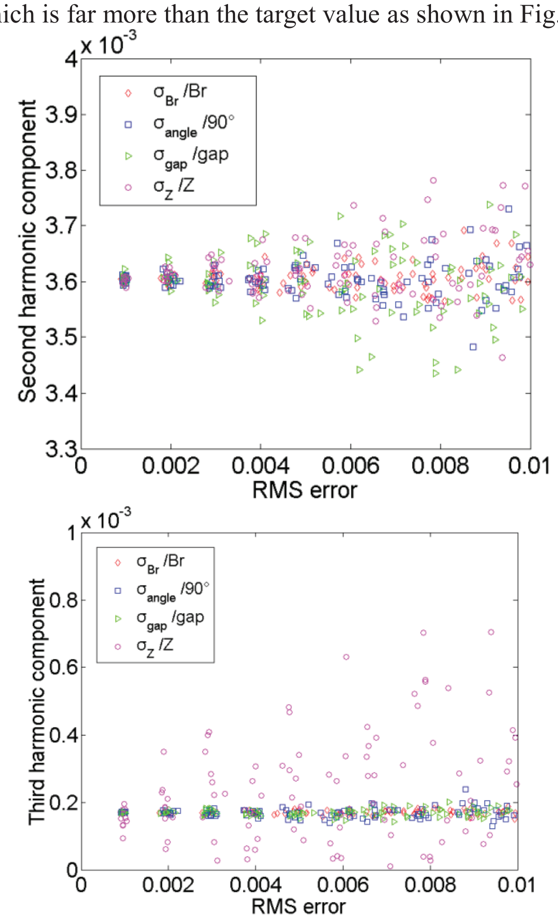

Figure 3: Demonstration of the influence of the PM errors on the harmonic component of the 2nd(upper) and 3rd (lower).The 2nd harmonic is larger than the 3rd. σ_{Br}/Br(red diamond), $\sigma_{angle}/90°$ (blue square), σ_{gap}/gap (green triangle) have little impact.

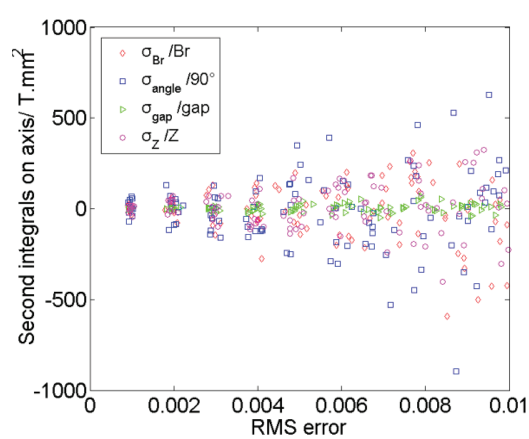

Figure 4: Demonstration of the influence of the PM errors on the second integrals. RMS gap height errors (green triangle) have little effect on field error second integrals.

ISBN 978-3-95450-122-9

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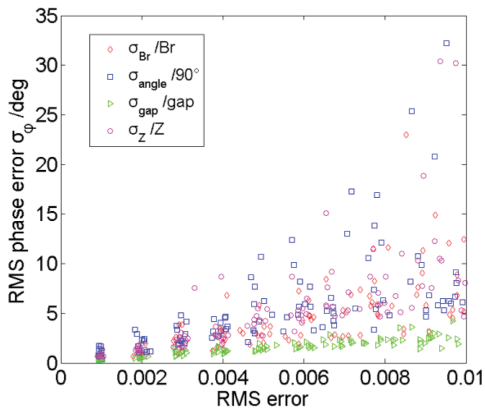

Figure 5: RMS phase error at different magnet errors. RMS gap height errors (green triangle) have little effect on field error second integrals.

The Phase error σ_φ has been deeply influenced by magnetization performance as shown in Fig.5. The phase error is approximately 2 ° when the errors are 0.1%. Requirements of PM blocks errors can be reduced by the magnetic field shimming technology.

Considering four errors systematically, the same error values have been assigned to each error type. The transfer coefficient of the peak field error is 1.47 that is less than the sum of the individual by simulation.

According to the demands of peak field error as well as phase error, the requirements of magnets are shown in Table 3.

Table 3: Tolerance Limits for the PM Specification

σ_{B_m}/B_m	σ_φ /°	σ_{Br} /Guass	σ_{angle} /°	σ_Z /μm	σ_{gap} /μm
≤0.2%	≤2	9.1	0.072	7	6.3
≤0.5%	≤5	22.8	0.18	1 7.5	15.8
≤0.8%	≤8	38.8	0.306	30.6	29.8

EFFECT OF WAVEGUIDE

To reduce the diffraction loss, a waveguide made of non-magnetic stainless steel is adopted in FEL. The 7 period undulator model with waveguide was established by FEM method, in which waveguide thickness is 5mm and relative magnetic permeability is 1.02 .The peak magnetic field will increase 4 Gauss corresponding to 0.08% of the undulator without waveguide.

According to formula (3), the magnetic pressure which the waveguide upper surface suffered is calculated and be shown in Fig. 6.

$$\frac{dF}{ds} = \frac{B^2}{2\mu_0}\left(1 - \frac{1}{\mu_r^2}\right) \tag{3}$$

Compared to undulator without waveguide in Fig. 7, second integrals decrease from -2.44 T • mm^2 to -8.85 T • mm^2 in undulator with waveguide. It cannot be ignored and can be rectified by correct coil.

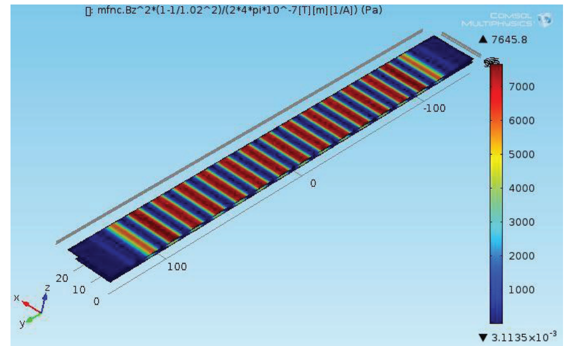

Figure 6: Distribution of electromagnetic pressure. It illustrates that the maximum pressure is up to 7645.8 Pa.

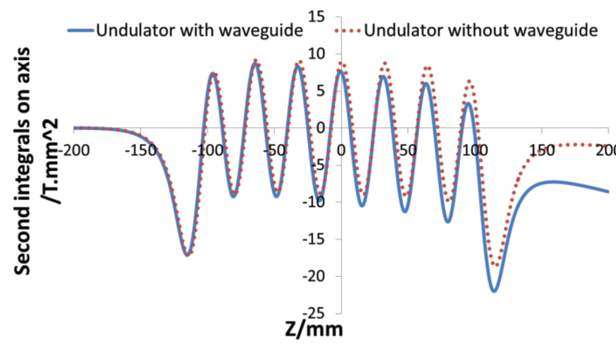

Figure 7: Second integrals on axis of 7-period undulator.

SUMMARY

Through calculation of undulator model created with errors in the Radia software, the impact of magnet errors on the performance of the magnetic field has been proposed. It provides a reference for the undulator processing and debugging and puts forward specific requirements for the material of the permanent magnet. However, it needs a mathematical analysis of error propagation coefficient as well as error synthesis in the future. The significant influence on magnetic field caused by waveguide is also discussed.

REFERENCES

[1] Qin, B., et al. "Design Consideration for a Hybrid Undulator applied in a Terahertz FEL oscillator." *MOPPP076, these proceedings*.

[2] Ge, CHEN Nian ZHANG Pengfei LI, XU Hongliang LI Yuhui ZHANG Shancai, and CAI Genwang HE Duohui. "Simulation study of influence of undulator magnetic field error on spontaneous emission." *Nuclear Techniques* 4 (2005): 002.

[3] Jia, Q. "Undulator phase deviation and shimming computation." *High Power Laser and Particle Beams* 10 (1998): 526-529.

[4] RADIA Technical Reference Manual, ESRF, Grenoble,France.

[5] Nikitina, Yu M., and J. Pflüger. "Influence of magnetic field errors on the spectrum of the PETRA undulator." *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment* 359.1 (1995): 89-92.

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