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MAGNETIC MEASUREMENT OF THE UNDULATOR U38 FOR THZ-FEL

L. G. Yan, D. R. Deng, P. Li, J. X. Wang, H. Zhang, M. Li, X. F. Yang
Institute of Applied Electronics, China Academy of Engineering and Physics, Mianyang, China

Abstract

The high average power terahertz free electronic laser facility (THz-FEL) has one undulator named U38. As one of the most important components, U38 has a significant effect on entire facility. So, we measure the magnetic field of U38 to confirm its field qualities using magnetic field measurement bench before installation. The measurement gaps include 19 mm, 21 mm, 24 mm, 25.6 mm and 28 mm, and the longitudinal distribution of magnetic field on five lines at transverse positions of -6 mm, -3 mm, 0 mm, 3 mm and 6 mm are scanned. Electronic trajectory, peak field vs gap curve and peak-to-peak error are calculated based on the longitudinal distribution of magnetic field. We also measure the transverse distribution of magnetic field to test the good field region. In this proceeding, the measurement method is described and the results are presented and discussed.

INTRODUCTION

The high average power terahertz source at CAEP (China Academy of Engineering Physics) is based on the routine of free electronic laser (FEL), which will output with the average power 10 W between the range of 100-300 μm. Undulator is one of the most important components in FEL and has a significant effect on spontaneous radiation, gain and saturation [1,2]. THz-FEL has one undulator named U38, which is manufactured by SINAP (Shanghai Institute of Applied Physics) at Shanghai. The magnetic structure of U38 consists of two standard Halbach-type permanent magnet arrays with period length 38 mm and gap range of 18-32 mm, which can generate max peak field of 0.55 T. Some errors must be decreased, such as peak-to-peak error (<1%), center trajectory deviation (<0.1 mm) and deviation error in 12 mm good field region (<0.5%) [3]. Before installation, it is indispensable to measure and characterize the magnetic field of U38 precisely in order to achieve high magnetic performances. In 2017, U38 is measured at Chengdu using magnetic filed measurement bench. In this proceeding, the measurement method is described and the results are presented and discussed.

INSTRUMENT AND METHOD

A magnetic field measurement bench (MFMB) has been constructed to confirm the field qualities of U38, which transports Hall probe through the undulator straightly and precisely. The figure 1 shows the measurement site. The total length of MFMB is 3 m, which is enough to measure 1.64-m-long U38. Positioning errors of MFMB are better than 10 μm in all three moving axis, which limits errors in the probe motion through the undulator and in turn decreases measurement errors. Before measurement, the rough alignment is done by laser tracker to parallel the three center planes of MMFB and U38, and then the fine alignment is done by measuring and analyzing the magnetic field in horizontal and vertical plane to fix the position of Hall probe in U38. MMFB works on go-stop mode with step length of 0.5 mm and pause time of 0.5 s. Local magnetic field is acquired by Bell 8030 that is a three dimensions Gaussmeter with accuracy of ±0.05%. The room temperature is controlled within 23±0.5 °C to minimize the field variation of U38 and ensure an acceptable stability of the MFMB.

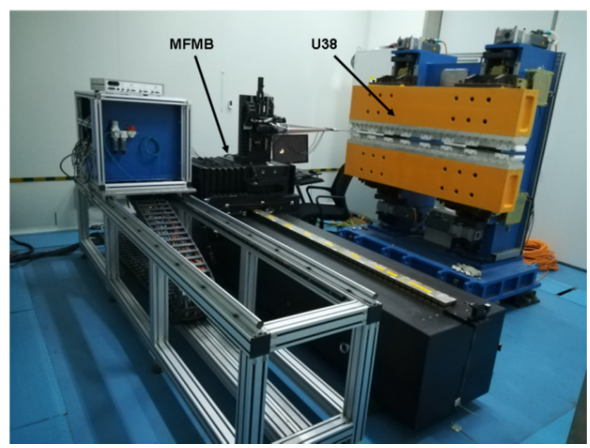

Figure 1: Measurement site.

RESULTS AND DISCUSSION

The vertical component of earth field in our lab is about 0.3 Gs. It is known a small field can influence undulating field obviously and then damage the straightness of trajectory. So, there is a long coil on both of upper and lower beam to cancel the residual dipole field and earth field in gap. In the following data, if not specified, the optimal current has been applied on the long coil.

The measurement gaps include 19 mm, 21 mm, 24 mm, 25.6 mm and 28 mm. We scan five lines in the transverse position from 6 mm to -6 mm with step length of 3 mm along the U38 at every gap. The total measurement points are 4600, which correspond to a measurement distance of 2.3 m. The margin length on both sides is 0.33 m.

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The Longitudinal Distribution of Magnetic Field

All the longitudinal distribution of magnetic field curves are sine-like and antisymmetric type. Due to limited paper space, we won't show raw measurement results except for gap 24 mm. Commonly, we can only get discrete magnetic field values because of the limited measurement points on the five lines in horizontal plane. Here, we concluded magnetic field at any point in the horizontal plane by two dimensions interpolation based on the discrete data that we have. The result at the gap of 24 mm is shown in figure 2(a), and the longitudinal distribution of magnetic field at the transverse position of 2 mm is concluded and shown in figure 2(b). There is similar case in other gaps, so we won't show more figures.

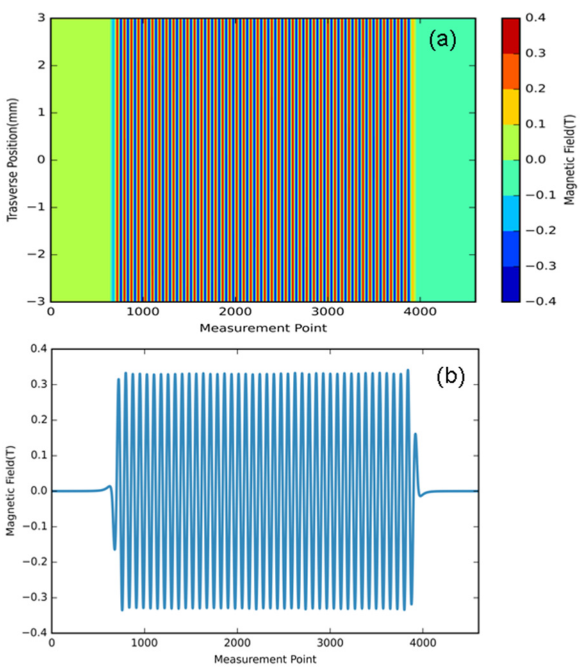

Figure 2: The magnetic field distribution in the horizontal plane (a) and at the transverse position of 2 mm (b) at the gap of 24 mm.

Electronic Trajectory

Electronic trajectory is calculated by integrating the longitudinal field distribution twice, in where the kinetic energy 8 MeV of electronic is applied. The trajectories at the transverse position from 6 to -6 is shown in figure 3. The center trajectory (transverse position 0 mm) must be less than 0.1 mm to ensure the overlap of electronic beam and light beam in FEL scheme. In the other transverse positions, we have added a offset in figure 3. It is obvious that there is a weak focus in the horizontal plane. So the transport matrix in horizontal plane is not a drift type but a focus type, which is different from the ideal case.

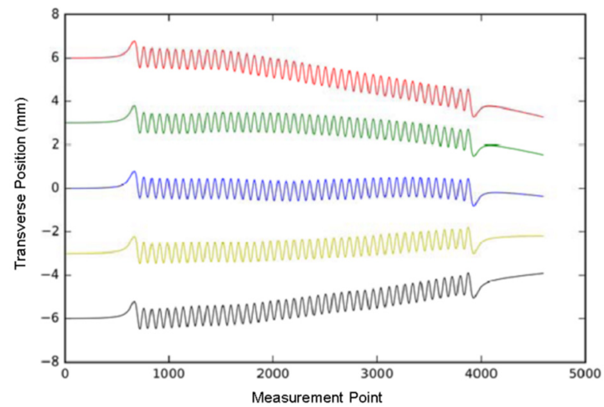

Figure 3: Electronic trajectories in the horizontal plane at the transverse position of -6 mm, -3 mm, 0 mm, 3 mm and 6 mm.

Peak Field vs Gap

The wavelength of radiation light is determined by peak field of undulator and energy of electronic, so a continuous curve of peak field and gap is needful in application. Commonly, the peak field of undulator decreases exponentially with increasing of the gap. In previous studies, equation (1) has been attained experimentally, in which B_0 is peak field, λ_u is period length, and g is gap. The three coefficients a, b and c must be determined with given undulator [4]. At every gap, the root mean square value of peak field of U38 is calculated from all of 84 ordinary peak field values, and then a, b and c is determined by fitting equation (1) using least square method (R^2=1). They are a=2.991, b=-3.736 and c=0.379. Figure 4 shows the raw data (red point) and the fitting curve (blue line). Now, peak field at any gap can be concluded by equation (1).

$$B_0 = a * e^{b*\frac{g}{\lambda_u}+c*(\frac{g}{\lambda_u})^2} \qquad (1)$$

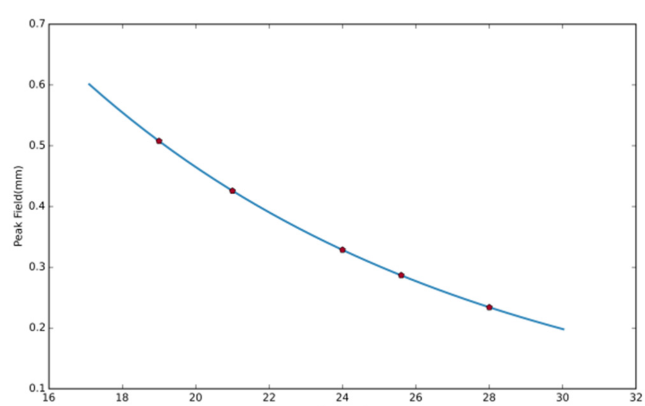

Figure 4: Peak field vs gap from 19 mm to 28 mm.

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Peak-to-peak Error

The peak-to-peak error is calculated by the root mean square value of peak field dividing mean value of peak field. The peak-to-peak error vs gap is shown in figure 5. All the errors are less than the required value of 0.5%. We also see the peak-to-peak error decreases with increasing the gap dramatically. It is because the influence of local error due to machining error and slight inhomogeneity of material on axis magnetic field becomes weak duo to the increase of distance of magnetic structure and horizontal plane.

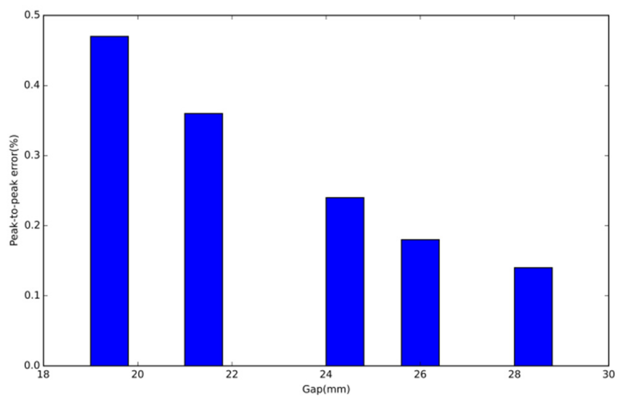

Figure 5: Peak-to-peak error at the gap of 19 mm, 21 mm, 24 mm, 25.6 mm and 28 mm.

Good Field Region

The width of magnetic structure must be wide enough to cover the width the transverse motion of electronic beam. In U38, 12 mm good field region with error of 0.5% is required. The transverse distribution of magnetic field between the transverse position of -18 mm and 18 mm is measured, which is show in figure 6. There is a flat-top at all of the measurement gap, and the error in good field region is below 0.5%.

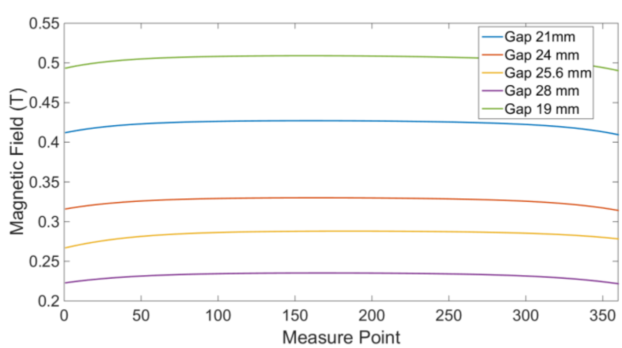

Figure 6: The transverse distribution of magnetic field.

SUMMARY

We measured the longitudinal and transverse distribution of magnetic field of U38 using magnetic field measurement bench to check its field qualities. Electronic trajectory, peak field vs gap curve and peak-to-peak error were calculated based on longitudinal distribution and good field region was concluded from transverse distribution. The results show that all the requirements of U38 are met.

ACKNOWLEDGMENT

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