PERFORMANCE ANALYSIS OF VARIABLE-PERIOD HELICAL UNDULATOR WITH PERMANENT MAGNET FOR A KAERI THz FEL

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Abstract

We could realize a variable-period (V-P) permanent-magnet helical undulator, which shows strong (~ 1 T) and constant field for the whole range of undulator period-length from 23 to 26 mm. This new compact and strong undulator will be used for developing a table-top high-power terahertz (THz) free-electron laser (FEL).

INTRODUCTION

A common way of tuning the undulator radiation wavelength is by varying the magnetic field of the undulator, which changes the *K* value. For a permanent-magnet undulator, the magnetic field strength is adjustable by changing the gap between the parts of the undulator. Another solution for wavelength tuning is variation of the undulator period-length [1, 2]. Recently, a V-P undulator was proposed with a planar structure using a split-pole structure of a hybrid permanent-magnet undulator [3]. The V-P undulator gives almost constant field strength at different periods, which results in less variations of a gain and radiation power for a given wavelength tuning range as compared with those for variable-gap undulators. The V-P undulator has a far less stringent dimensional tolerance and less driving force as compared to those for the variable-gap undulator, as it is shown in Ref. 3.

DESIGN AND FABRICATION

The concept of the design is based on the structure of the hybrid permanent-magnet planar undulator.

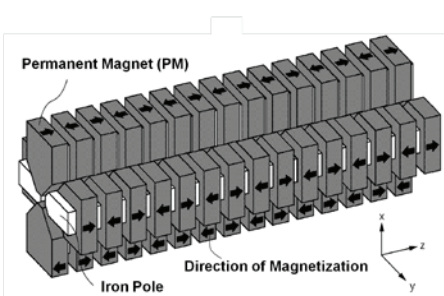

Figure 1: Magnetic design of the V-P helical permanent-magnet undulator [4].

Table 1: Main Parameters of the V-P Helical Permanent Magnet Undulator for a Compact THz FEL [4].

Gap	5 mm
Number of periods	30
Length of period	23-26 mm
Peak magnetic field	1 T

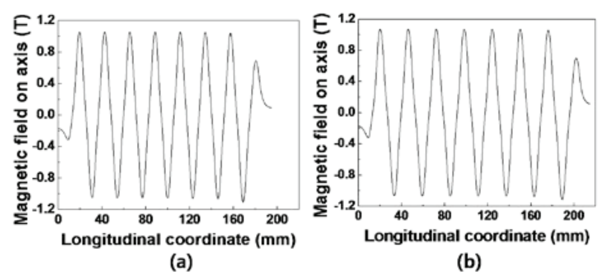

Figure 2: Calculated vertical component of the on-axis magnetic field of the V-P helical undulator. (a) λ_w = 23 mm and (b) λ_w = 26 mm. The calculated peak magnetic field is about 1 T [4].

This helical undulator is a combination of two planar undulators. A three-dimensional (3-D) simulation of the V-P helical undulator using the CST code [5] for different undulator period lengths was carried out. Table 1 shows the main parameters of our V-P helical undulator for a compact THz FEL. Figure 1 shows the structure of the V-P helical undulator, consisting of permanent magnets and iron poles. A short undulator with seven periods was then simulated for λ_w = 23 mm and 26 mm, where λ_w is the undulator period-length. In this simulation, the sizes of the magnets and poles were fixed. Only the period length of the undulator was varied. Figure 2 shows the simulated vertical component of magnetic field on the axis of the V-P helical undulator. According to the results of the simulation, the peak magnetic field on the undulator axis almost does not depend on the period length. Thus, the V-P helical undulator enables us to tune FEL wavelength without significant degrading the FEL gain.

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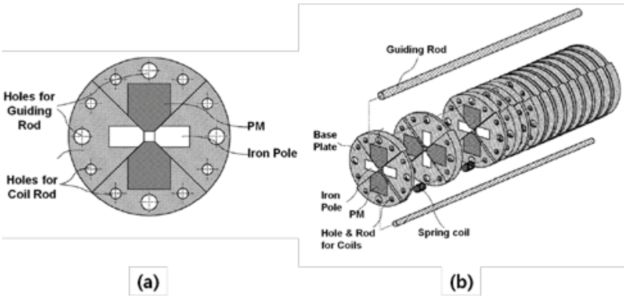

Figure 3: (a) Schematics of a basic module of the V-P helical permanent-magnet undulator. The module contains two permanent magnets and two iron poles. (b) Assembly configuration of the undulator [4].

A magnetic basic module composes of two permanent magnets and two iron poles on a non-magnetic plate, which corresponds to the 1/4 of the undulator period, as shown in Fig. 3. The using permanent magnets are NdFeB which has the remanent flux density of about 1.2 T. The modules are successively installed with the rotation by of 90-degree. Four such rotated modules form one period of the undulator. The basic modules are set through the guiding non-magnetic rods. Each modular plate has longitudinal repulsive force by the bigger permanent magnets than iron poles and also, we strengthen the force with the aid of spring coils between the modular plates. By simply controlling the longitudinal position of one end modular plate of the undulator by using a linear moving stage, we can change the period of the undulator because all modular plates are spaced regularly by the repulsive force. The period lengths of the undulator can change by using a mechanical motorizing system.

FIELD DISTRIBUTION AND PERIODICITY MEASUREMENTS

For the analysis of the field distribution and periodicity of the V-P helical undulator, the field measurement was performed by using a transverse Hall sensor (Lakeshore Inc.). Figure 4 shows the measured values of the vertical field component on the undulator axis at a period length of 26 mm. The measured and simulated values are in good agreement. The measured average peak magnetic field is 0.96 T. The difference of this value from the calculated one is less than the uncertainty of the permanent-magnet magnetization.

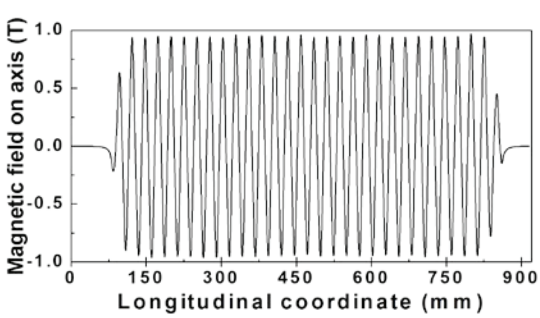

Figure 4: Measured vertical component of field on the undulator axis at the period length of 26 mm.

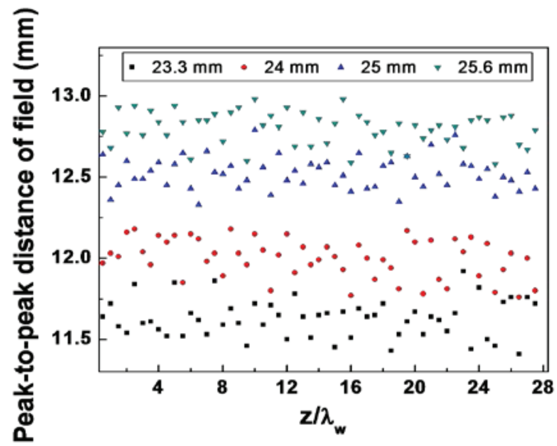

Figure 5: Measured peak-to-peak distances for four undulator periods [4].

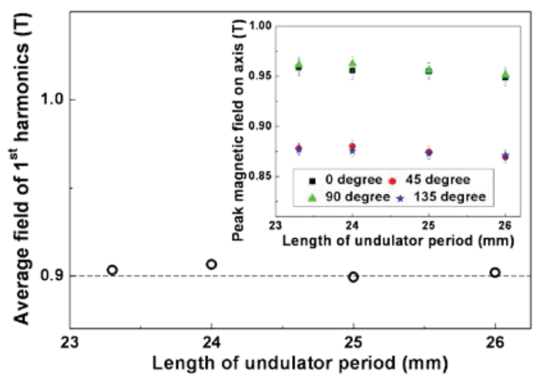

Figure 6: Dependence of the average fundamental harmonics of magnetic field on the period length of the V-P helical undulator. The inset graph of the figure shows the peak magnetic field on the undulator axis [4].

The new feature of this V-P undulator is the variable positions of poles and magnets. Therefore, it was interesting to measure the corresponding aperiodicity of the field. Figure 5 shows the periodicity measurements of the V-P helical undulator for period lengths of 23.3, 24, 25, and 25.6 mm. We estimated the period through the analysis of distances between the maxima of the measured magnetic field component. The r. m. s. deviation of the peak-to-peak length in each case was less than 1%. Figure 6 shows the dependence of the average fundamental harmonics of magnetic field on the period length of the V-P helical undulator. The inset graph of the figure shows the deviation of the peak magnetic field along the undulator axis for each period length. The r. m. s. deviation of the peak field module for each period length was measured to be less than 0.7%. The first and the second field integrals and the corresponding radiation Fourier harmonics [6] were calculated. Calculated ratio of the maximum spectral intensity of radiation to the ideal one and r. m. s. phase errors are presented in Table 2.

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Table 2: Spectral Intensity, normalized to the ideal one, and r. m. s. phase errors for different undulator periods [4].

Period (mm)	Spectral intensity ratio (%)	R.m.s. phase errors (degree)
23.3	98	2.7
24	95	8.0
25	98	3.6
25.6	97	3.7

The reproducibility of the phase error was checked by measuring the field six times at 25.6 mm period after random shifts of undulator sections. The mean value of the r. m. s. phase errors is 3.7. The results of these calculations show, that the field errors are within the tolerances for a table-top THz FEL.

CONCLUSION

This undulator has several advantages as below. First, tuning of the radiation wavelength without decrease of the undulator field is possible by adjusting the undulator period. Second, the helical permanent magnet undulator can generate strong field on the undulator axis. Third, realization of a compact and mechanically simple system is possible. Fourth, the V-P undulator enables us to tune the FEL wavelength and to reduce the size of the undulator without degrading the FEL gain. Consequently, this strong and compact undulator may be a useful technology for the development of a new FELs and cost effective insertion devices for synchrotron radiation sources.

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