

## Effects of Design Parameters on Magnetic Fields Generated by Synchrotron Undulator

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### Abstract

Magnetic fields from a planar undulator for a synchrotron source are simulated by using Radia program. The undulator consists of 4 arrays of permanent magnets. Each array has 41 bars of magnet whose remanent magnetization is perpendicular to the adjacent one. The simulated magnetic field is periodic and dependent on configuration of the magnets including the gap and the magnetic period length. Magnetic field can be adjusted by translating an array of magnet relative to each other. The variation of this field with the translation is symmetric with respect to its direction. By the calculation of the force from the simulated magnetic field, the zig-zag electron trajectory in the horizontal plane is obtained and leads to the synchrotron radiation.

**Keywords:** Undulator, permanent magnets, synchrotron radiation, magnetic field simulation

### Introduction

In 2001, the Siam Photon Source has first produced synchrotron light in Thailand. Now, the facility is equipped with beam lines for photoemission spectroscopy, photoelectron emission microscopy, x-ray lithography, x-ray fluorescence, x-ray absorption spectroscopy and small angle x-ray scattering and has increasing contributions in material science, biomedical science, physics, chemistry and biology research [1-4]. In the synchrotron facility, electromagnetic wave of high intensity and brilliance is emitted by electrons, accelerated closed to the speed of light, in the bending magnets around the storage ring. Some applications of the synchrotron radiation such as soft x-ray spectroscopy, spin-resolved photoelectron spectroscopy and magnetic circular dichroism require either circularly polarized light or variably polarized light. In order to meet these requirements, the Siam Photon Source needs insertion devices in a straight section of its storage ring. Insertion devices are classified into 2 types according to their wiggler strength (K) [5].

$$K = 0.934 B_0 \lambda_p \quad (1)$$

where  $\lambda_p$  is the magnetic period length and  $B_0$  is the peak magnetic field. The device with a low wiggler strength ( $K \ll 1$ ) is called undulator. The undulator offers a high intensity light whereas the wiggler, the other type of insertion device with a larger wiggler strength, is often used when the high photon energy is needed [5].

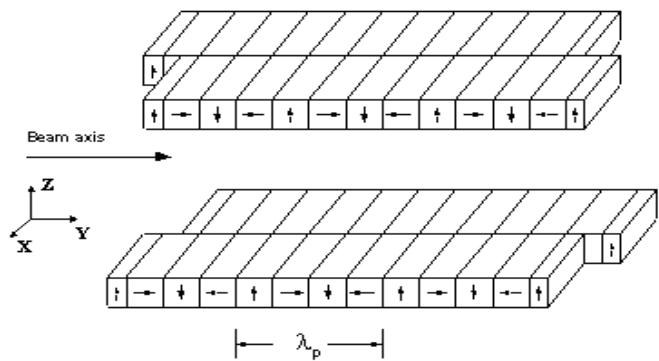
Planar undulators, permanent magnet based devices, are installed in synchrotron facilities worldwide [6-8]. In a design called APPLE II (Advanced Planar Polarized Light Emitted) [6], there are 4 rows of magnetic bars. Two rows are placed above electron beams and parallel to the other 2 rows beneath them. In each row, the magnetization of each magnetic

bar is perpendicular to the adjacent one. Electrons travel in the gap between the rows of magnets have helical trajectory due to periodic magnetic fields in horizontal and vertical directions. As a result, high intensity x-rays are emitted whose polarization is changed by translating a row of the magnet relative to the other.

Before constructions, magnetic fields in any insertion devices have to be calculated. Radia, a freeware developed by researchers at European Synchrotron Radiation Facility since 1997 [9], offers a convenient and efficient way for such simulations. The program, coded by object-oriented C++ with Mathematica user interface, employs boundary integral method to calculate magnetic fields from either electromagnets or permanent magnets. A previous study on undulators showed that it gave similar results to the simulation by a Fortran code [10]. Its versatility extends to the possible calculations of magnetic field in other devices. In this work, we implement Radia to show magnetic fields and resulting electron trajectories in a planar undulator

## Methods

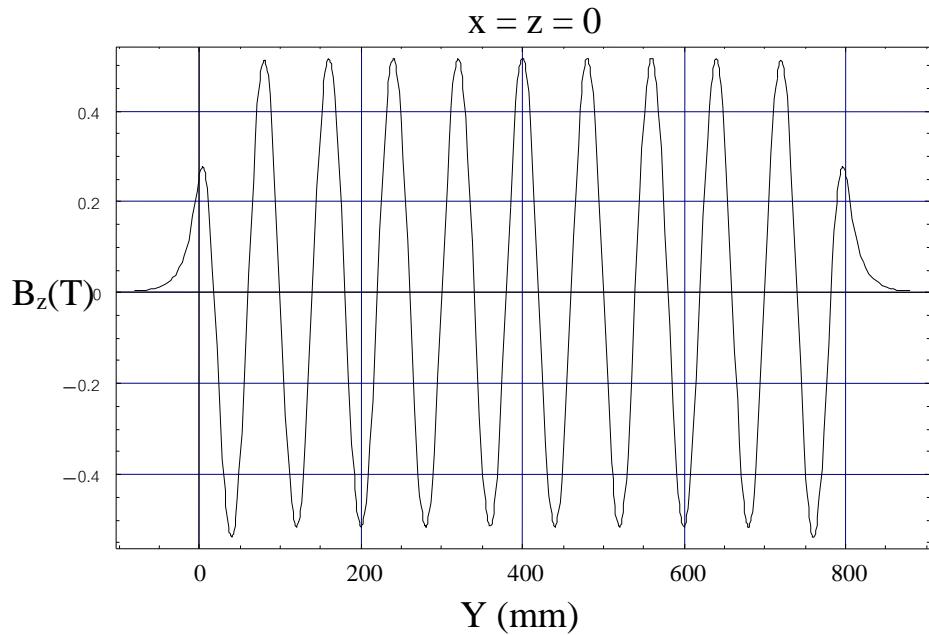
To simulate the magnetic field from the APPLE planar undulator, 4 arrays of permanent magnets are drawn on Radia. Their geometry and the coordinates are indicated in Figure 1. Each array has 41 magnets (only 12 bars are exemplified in Figure 1) whose dimensions are  $100 \times 20 \times 25 \text{ mm}^3$ . The remanent magnetization of the magnets is set at 1.38 T, which is realistically obtainable in Nd-Fe-B based permanent magnets. For an exception, the bars at both ends are smaller and supply weaker field than the rest in the array to compensate the orbit distortion of electrons [5]. The magnetic field is calculated as a function of several parameters namely an undulator gap (Gap), magnetic period length ( $\lambda_p$ ) and the length of array translation (ID Length). In additions, the relation between the magnetic pole width and the maximum magnetic field, also known as peak field, is studied. Finally, the trajectory of an electron in this magnetic field can also be calculated from the force acting on it.



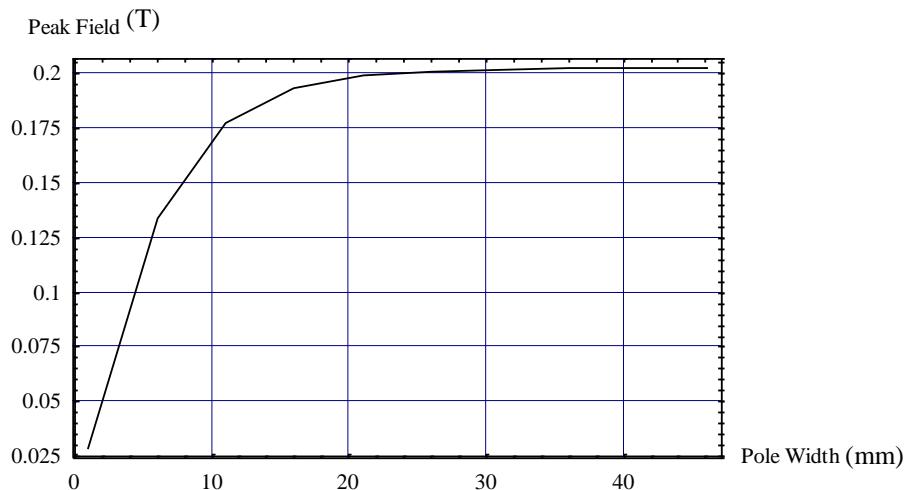
**Figure 1** Diagram of planar undulator.

## Results and discussion

By setting the conditions  $x = z = 0$ , Gap = 10 mm,  $\lambda_p = 80 \text{ mm}$ , the vertical magnetic field ( $B_z$ ) along the y-axis shown in Figure 2 for 10 periods (Nper = 10) is periodic. The field has its peaks around 0.5 T. From such figures, the peak field can be deduced in the case of varying pole widths at a constant gap of 30 mm. The peak field in Figure 3 has roughly linear variation with the pole widths of less than 5 mm. The sensitivity of peak field to the change in pole width is reduced from 5 mm and approached saturation from 20 mm. This justifies the selection of magnets' size in Figure 1.



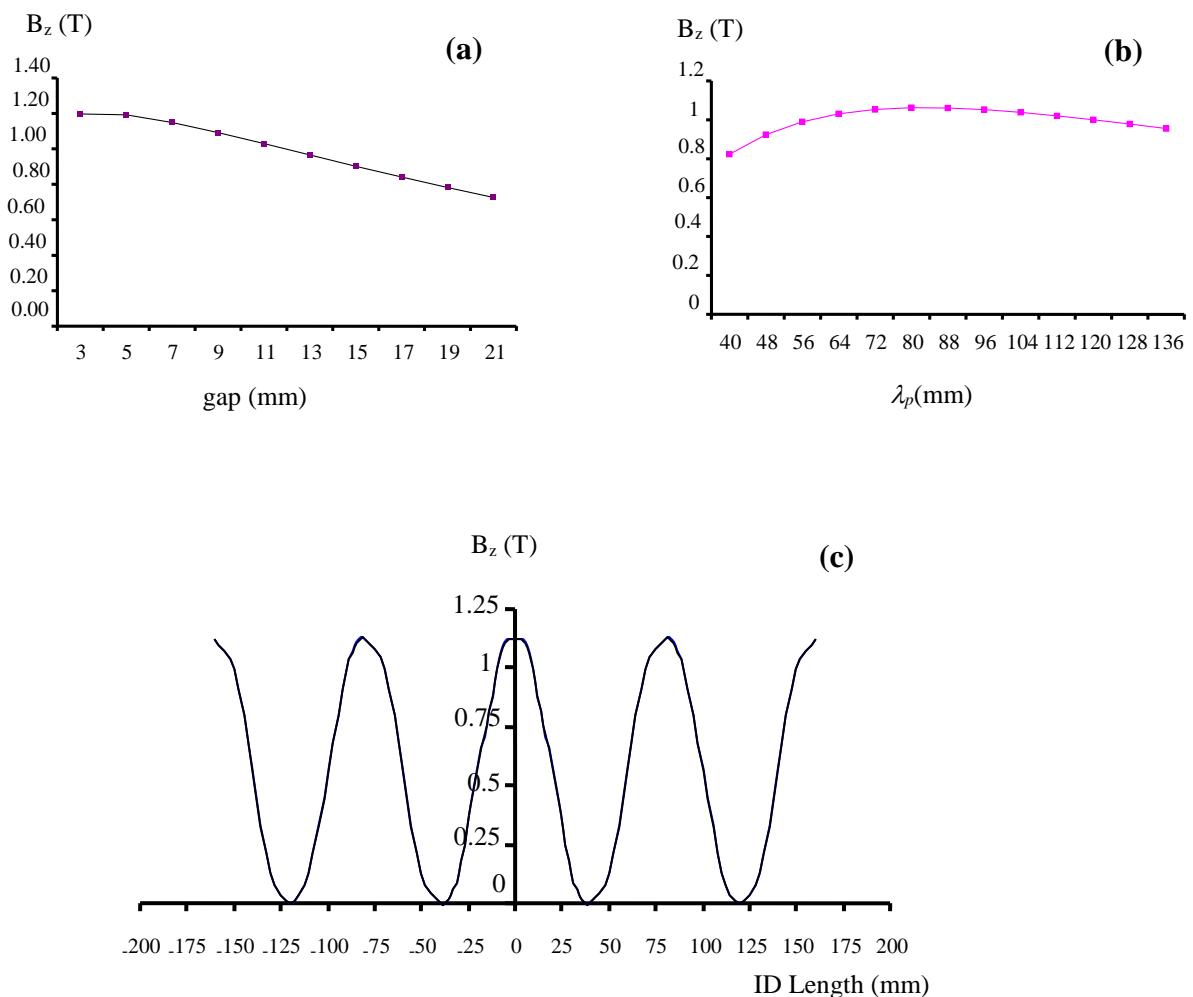
**Figure 2** Simulated vertical magnetic field along the  $y$ -axis in planar undulator.



**Figure 3** Peak field obtained from undulator by simulation as a function of pole width.

The dependence of  $B_z$  on Gap,  $\lambda_p$  and ID Length is shown in Figure 4. The  $B_z$  is about 1.2 T in the case of 3 mm gap and steadily decreased with increasing gap from 5 to 21 mm as shown in Figure 4(a). The trend can be easily understood because the arrangement with magnets closer each other should lead to higher magnetic fields. However, it must be taken into account that the gap larger than 20 mm is typically required to accommodate vacuum pipes of the real storage ring. In contrast to the dependence on the gap,  $B_z$  in Figure 4(b) is not monotonically changed with  $\lambda_p$ . It initially increased with  $\lambda_p$  up to 70 mm, attaining the maximum and then gradually reduced with the further increase in  $\lambda_p$ . It follows that  $\lambda_p$  between 70 and 90 mm is preferred in the constructions of undulators of this design. By setting the conditions for large  $B_z$  (Gap = 10 mm,  $\lambda_p$  = 80 mm),  $B_z$  is plotted as a function of ID length in Figure 4(c). The field is periodic with a maximum value of 1.2 T and, hence, symmetric to the direction of the translation.

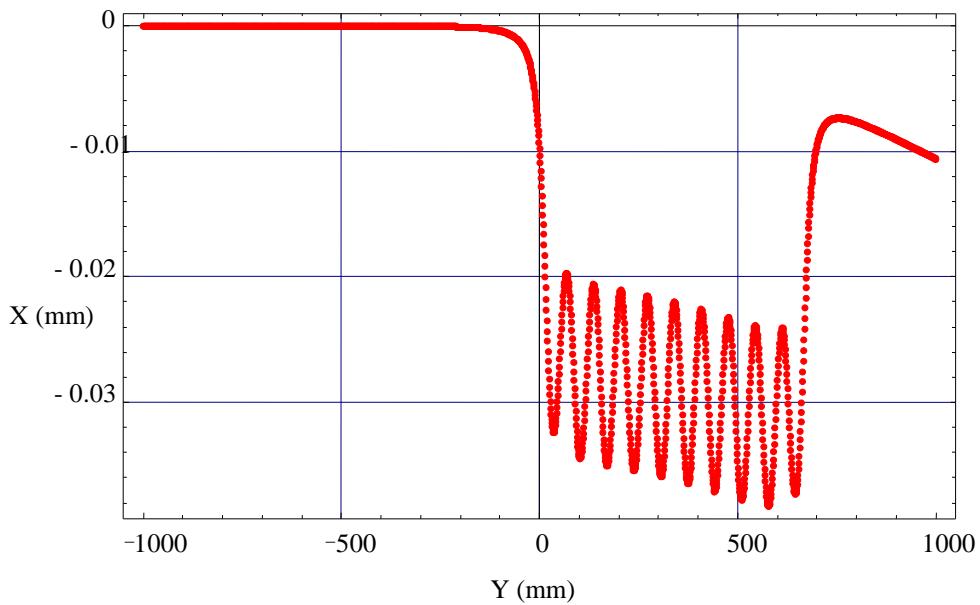
In a similar fashion, the horizontal magnetic field can also be simulated. In Figure 5, an electron follows a zig-zag path in the horizontal (x-y) plane of the helical planar undulator. Such deviation of electrons in response to magnetic field in the undulator is required for synchrotron radiation because the bending of relativistic electrons leads to the soft x-ray emission. Moreover, the photon energy from the synchrotron radiation can be calculated from the peak field which is beyond the scope of this work.



**Figure 4** Peak magnetic field in the z-axis as a function of (a) gap, (b) period and (c) ID-length.

### Conclusions

From simulations by Radia program, the magnetic field from the planar undulator and hence the electron trajectories in this insertion device are dependent on the gap, the magnetic period length and the translation of magnetic array. The magnetic field is periodic and reduced with the gap. To obtain large magnetic fields, the optimum length of magnetic period and translation can be found from the simulation.



**Figure 5** Calculated electron trajectory in horizontal plane of planar undulator.

### Acknowledgments

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