ISBN: 978-3-95450-265-3 doi:10.18429/JACoW-SAP2023-MOPB003

STUDY ON A POLARIZATION CONTROLLABLE UNDULATOR FOR HIGH-GAIN FREE ELECTRON LASERS *

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Abstract

SASE FEL can generate intense and coherent linearly-polarized X-ray when high energy electron beams travelling through a long planar undulator. It is also of great importance and interest to control the polarization of FEL. One possible solution is utilizing a customized undulator to adjust the magnetic field direction. By tuning the displacement of the magnetic block arrangement, variation of polarization could be achieved. In this paper we study on a polarization controllable undulator to realize the variable polarized magnetic field. Different shapes and design considerations of the magnetic block configuration will be introduced. The value of peak field and the region of good field will be analysed and discussed.

INTRODUCTION

The X-ray free electron laser (FEL) have the ability to explore the ultra-small and ultra-fast regime. Self-amplified spontaneous emission (SASE) is intense and coherent radiation via an extremely high gain process. SASE FEL usually produces linearly polarized radiation based on planar undulators. The light source polarization is one of the key characteristics of the radiation. Furthermore, arbitrarily polarization control has great application requirement, such as in developing powerful probing spectroscopies [1] and performing circular dichroism experiments [2]. A helical undulator could be used to achieve circular polarization, while challenging to change the polarization between two diametrically opposed helices. Another method to obtain control of polarization is to use a dedicated planar undulator. By tuning the relative displacement between upper and lower magnet array, the phase of the electromagnetic field is shifted and the field strength is adjusted, turning out the polarization change. In this manuscript, we will give the study of different shapes and design considerations of the magnetic block configuration.

MAGNETIC STRUCTURE

We have studied a novel variable elliptical polarization undulator with different structure arrangement considered. In the original design, the pure permanent magnetic blocks are periodically arranged with four upper and lower blocks. In each period, two opposite horizontal magnetization of magnets and two opposite longitudinal magnetization of magnets are placed at intervals. The displacement of upper and lower magnet arrays can be mechanically shifted. As a result, a horizontal polarization, a vertical polarization and an elliptical (or circular) polarization can be realized separately. Several magnetic block shapes are considered as shown in Fig. 1.

The magnetic design is performed via the Radia package [3]. In one design specification of the original structure, the simulation results for different polarization modes of the transverse magnetic field distribution on the longitudinal axis are shown in Fig. 2. Undulator parameters of the original block and displacement shift requirement on polarization change are listed in Table 1. The peak field of the periodic distribution can reach above 0.4 T for linear polarizations, and above 0.3 T for circular polarization. Although there is field deformation at ends of the undulator, it can be improved by optimization of the edge blocks. However, the uniform region very small for this original structure. Some techniques have been suggested to improve the transverse field homogeneity [4,5]. We study on three design considerations.

Table 1: Main Parameters of the Original Block Design

Parameter	Specification
Period	100 mm
Number of periods	10
Gap(fixed)	20 mm
Magnet block size(width*height)	60*60 mm
Vertical peak field	0.42 T
Horizontal peak field	0.44 T
Peak field at circular polarization	0.33 T
Shift of vertical polarization	0 mm
Shift of horizontal polarization	50 mm
Shift of circular polarization	35.6 mm

Side-block Arrangement

In the side-block arrangement, magnet blocks of vertical magnetization are added at both width end of the horizontal magnetization blocks to compensate the region of good field. By proper optimize the geometrical parameters, the uniform field region is increased from less than 0.1 mm to 1.0 mm in horizontal and 1.8 mm in vertical, under field homogeneity $\Delta B/B \leq 0.5\%$.

We fix the size of the main magnets and the height of the side blocks, then compare the peak field and the uniform

* Work supported by the National Natural Science Foundation of China (Grant Number 12175224, 11805200).
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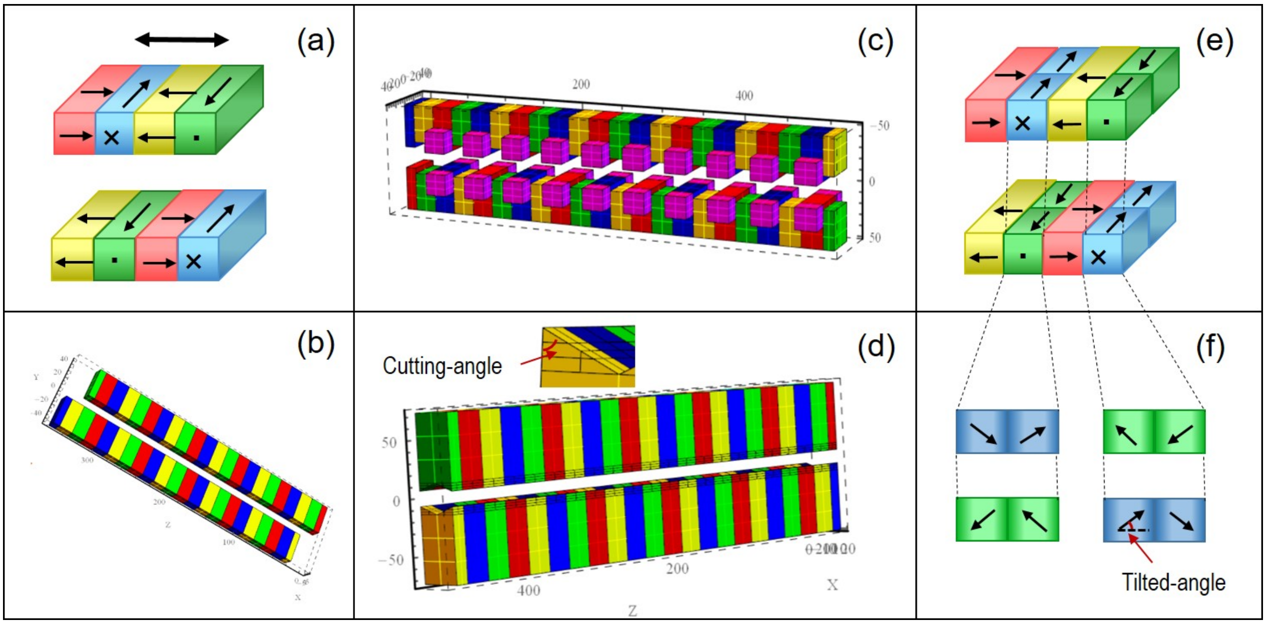

Figure 1: Several magnetic block shapes: the original block with diagrammatic drawing of magnetization directions in (a) and structure arrangement in (b); the side block arrangement in (c); the wedge block arrangement in (d); the tilted magnetization arrangement with diagrammatic drawing of solid figure (e) and with right side views of horizontal magnetized blocks

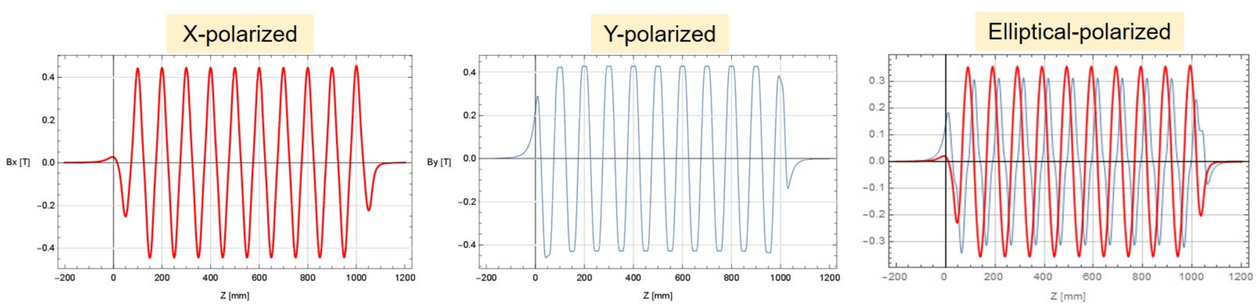

Figure 2: Simulated transverse magnetic field distribution in one original design specification. Left: horizontal polarization mode; Middle: vertical polarization mode; Right: elliptical polarization mode.

field region by varying the size of the side magnets, as shown in Fig. 3. In the veritcal polarization mode, the width of side magnets minimally affect both the peak field and the uniform region. In the horizontal polarization mode, when the width decreases the B_x field is reduced and good region increased. It is notable that the uniform field region in horizontal can be larger than 8 mm.

Wedge-block Arrangement

In the wedge-block arrangement, the magnet block has a wedge towards the beam axis. In this design, the wedge angle as well as the size of the folded surface's horizontal area should be optimized. Firstly, to balance the uniform field region on both planes, the horizontal length of the folded surface area should be zero or small enough.

We define the cutting-angle as labelled in Fig. 1 (d). If the wedge angle is varied, the magnetic field and its good region will also be changed. As shown in Fig. 4, when the cutting-angle increases the vertical field is increased and good region increased. While the good region and peak field of the horizontal mode is not optimized.

Tilted-magnetization Arrangement

In the tilted-magnetization arrangement, the horizontal magnetized block is divided into two with a certain magnetized tilt angle as shown in Fig. 1 (e) and (f). The tilted-angle has a clear impact on the peak field and the homogeneity field region. When the tilted-angle is arctan(0.2), the field distribution for horizontal and vertical polarization modes are shown in Fig. 5. The horizontal peak field is reduced to about 0.08 T, while the vertical peak field can be maintained above 0.34 T. The uniform field region under field homogeneity $\Delta B/B \leq 0.5\%$ is increased to 1.8 mm in vertical, while reduced to 0.08 mm in horizontal.

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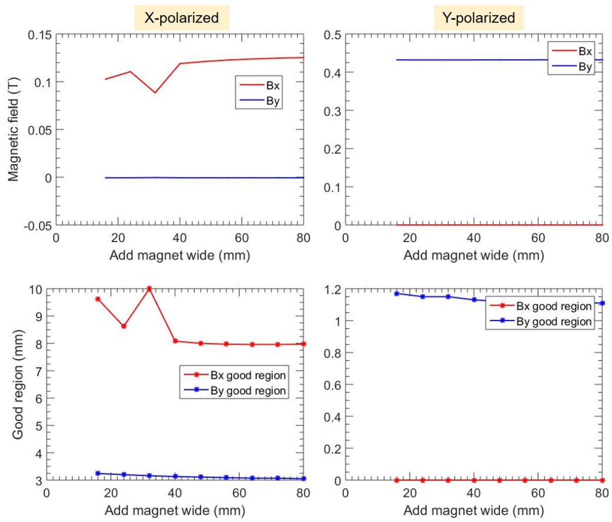

Figure 3: The peak field (upper) and the uniform field region (lower)for side-block arrangement for different sizes of the side magnets. Left: horizontal polarization mode; Right: vertical polarization mode.

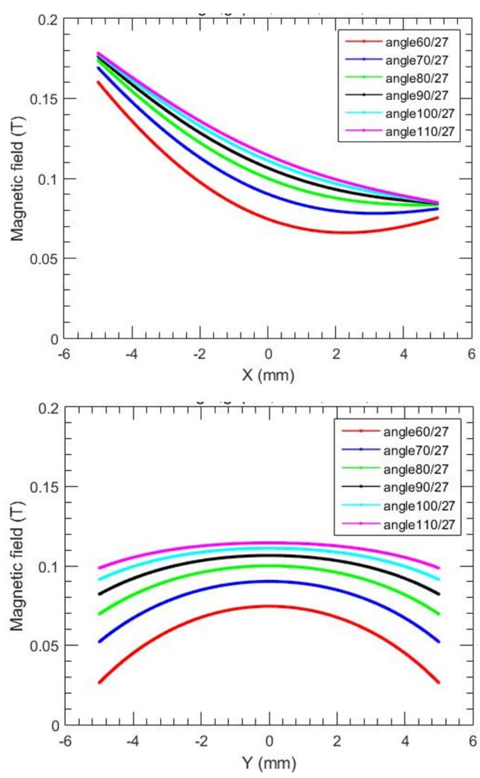

Figure 4: The transverse field distribution of wedge-block arrangement for horizontal polarization mode (upper) and vertical polarization mode (lower).

CONCLUSION

Various block layouts have been investigated to realize adjusting of the polarization and broadening the homogeneity field region. By tuning the relative displacement between upper and lower magnet array, the phase of the magnetic field can be changed bringing out polarization control. Among

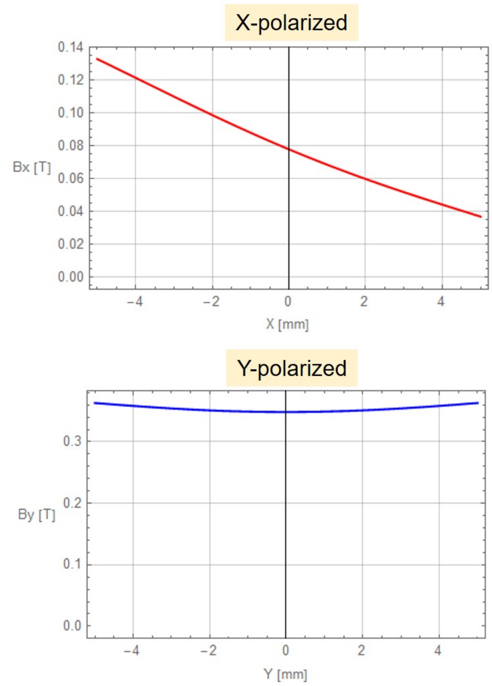

Figure 5: The transverse field distribution of tilted-magnetization arrangement for horizontal polarization mode (upper) and vertical polarization mode (lower).

those block shapes, the side-block arrangement can achieve considerable uniform field region in both polarization modes especially in horizontal plane. While the peak field of horizontal polarization is fairly lowered. The good region under field homogeneity $\Delta B/B \leq 0.5\%$ can be larger than 8.0 mm in horizontal and 1.1 mm in vertical at the expense of B_x descent. More magnet structures should be investigated to further improve the undulator field properties.

REFERENCES

[1] L. E. MacKenzie *et al.*, "Rapid time-resolved Circular Polarization Luminescence (CPL) emission spectroscopy", *Nature Communications*, vol. 11, no. 1676, 2020. doi:10.1038/s41467-020-15469-5

[2] R. Hussain *et al.*, "Circular Dichroism and Synchrotron Radiation Circular Dichroism Applications to Biomaterials", *Radiation in Bioanalysis*, vol. 8, pp. 147–172, 2019. doi:10.1007/978-3-030-28247-9_5

[3] Radia software, http://www.esrf.fr/machine/groups/insertion_devices/Codes/Radia/Radia.html.

[4] C.S. Hwang *et al.*, "Magnet block arrangements for the APPLE-II elliptically polarized undulator", in *Proc. of PAC07*, pp. 1079–1081, 2007. doi:10.1109/PAC.2007.4440988

[5] T. Wang and Q. Jia, "Study of Magnetic Block Arrangement of APPLE-II undulator", in *Proc. of EPAC08*, paper WEPC152, 2362–2364. https://accelconf.web.cern.ch/e08/papers/wepc152.pdf