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Magnetic Field Optimization of a Novel Hybrid Permanent Undulator

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Abstract. A novel hybrid permanent magnet undulator with a short period length is introduced and the optimization procedure for the magnet dimension is described in this paper. The simulation result shows that the effective peak field of the undulator with the period length of 16 mm can be greater than 1.6 T at the pole gap 4.2 mm when the magnets operate at the cryogenic temperature with the remanence of 1.5 T.

INTRODUCTION

Short period undulators are of particular interest for next-generation synchrotron radiation facility and XFEL facility because they increase the number of periods in a given undulator length and generate brighter radiation light. A short-period undulator, moreover, can produce higher energy photons for the x-ray beam line in a lower electron beam energy accelerator. But, in general, when reducing the undulator period length, the dimensions of each magnet piece become smaller and the undulator should be operated at smaller magnetic gaps to obtain sufficient magnetic field [1]. The in-vacuum undulator developed about 20 years ago can greatly improve the peak field of the short-period undulator because the magnet arrays are placed inside the vacuum chamber and the gap can be very small. But the undulator gaps are limited by some issues such as the wake field effects and the radiation damage. The cryogenic permanent magnet undulators (CPMUs) developed in recent years improve the peak field of the short-period undulator further more by increasing the remanence of the permanent magnets when operating at the cryogenic temperature of the liquid nitrogen or higher. In 2017, Shanghai Synchrotron Radiation Facility (SSRF) [2] successfully developed a cryogenic permanent magnet undulator with NdFeB permanent magnets. The undulator magnets have a hybrid structure with a 20 mm period, period number 80, minimum magnetic gap 6 mm, and the effective peak magnetic field is 1.03 T. A year later, a cryogenic permanent magnet undulator based on PrFeB permanent magnets was successfully developed, period length 18mm, period number 144, minimum magnetic gap 6 mm, and the effective peak magnetic field is 0.91 T [3]. Another prospective technology is superconducting undulator. It can obtain higher peak fields but there are some big technological difficulties such as the thermal budget problem. Comparing to the superconducting undulators, the permanent magnet undulators are widely used because of its mature technology and low cost.

MAGNET CONFIGURATION

Two types of Halbach magnet configuration are commonly used in permanent magnet undulators: pure permanent magnet undulator (PPMU) and hybrid permanent magnet undulator (Hybrid PMU). In the Hybrid PMU, each pole which is made from the soft iron is magnetized by two permanent magnet blocks and generally the peak field is greater than that of a PPMU with the same period length and same gap especially for the undulator with small ratio of gap to period length. The peak field of the Hybrid PMU can be expressed as [4]:

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$$B_0 = ae^{-b\frac{g}{\lambda_0}+c\left(\frac{g}{\lambda_0}\right)^2}$$

Where λ_0 is the period length, g is the gap. For example, for an undulator with the period length of 20 mm and the Sm_2Co_{17} magnet, Br=1.1 T, a=3.44, b=5.08, c=1.54, the peak field at the gap of 5mm is 1.06 T. For a cryogenic permanent magnet undulators CPMU18 developed at SSRF recently with the PrFeB material which has the remanence Br=1.5 T at the temperature of 77 K, a=3.66, b=4.3, c=1.02 can be fitted from the magnetic field measurement results and the peak field of 1.33 T can be obtained at the gap of 4.5 mm.

In previous conventional Hybrid PMU, permanent magnets and soft irons were staggered along the beam direction, and the size of the soft iron was always smaller than that of the permanent magnets. The HZB [5] laboratory has increased the magnetic field by adding permanent magnets at both sides of the pole. In our case, another magnet block is added on the top of the pole and the faces near the beam axis of the side blocks are inclined to shape a polygon beam tunnel and all magnet blocks are of trapezoid shaped, as shown in Figure 1. The small gap between the upper and lower side magnets increases the peak field on axis greatly. The dimensions of the magnets and the poles are optimized to get the maximum peak field for a CPMU with the period length 16 mm and the pole gap 4.2 mm. The magnet material is NdFeB with the type of N38EH and the pole is made of the cobalt vanadium iron.

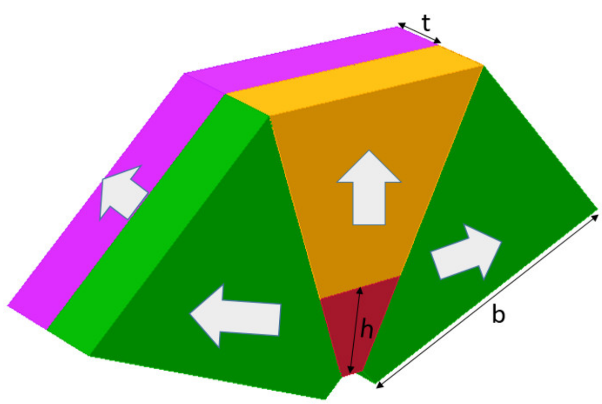


FIGURE 1. The novel hybrid PMU configuration (1/2 period of upper).

MAGNETIC FIELD OPTIMIZATION

All the magnets and poles are isosceles trapezoids and the angle between the bevels is 45°. The short sides of the two side magnet blocks and the pole are 1.74 mm and a beam tunnel with the inscribed radius of 2.1 mm is shaped. The remanence Br of the N38EH can be 1.45~1.5 T at the temperature of about 130 K. At the room temperature, the remanence Br is 1.25 T and the intrinsic coercivity Hcj is about 34.6 kOe. The object to optimize is to get the maximum effective peak field and the minimum roll-off of the peak field at the low temperature 130 K and the minimum demagnetizing field in the magnet blocks at the room temperature. The optimized variables include the bevel b of the side magnets, the height h of the pole and the thickness t of the horizontally magnetized blocks (H-Block), and the magnetization direction θ of the side magnets, as shown in Figure 1. The magnetic fields are simulated by the module TOSCA of the OPERA-3D software. The variations of the effective peak fields versus the variables are shown in Figure 2. The roll-off of the peak field can be optimized by tuning the magnetization direction θ of the side magnets. Figure 3 shows the roll-offs with three different θ. As a result, we take b=20.7 mm, h=6 mm, t=3.9 mm, and θ=20.7°. The effective peak field is about 1.655 T and the roll-off is less than 1×10^{-4} within the good field region of ±0.5 mm. It is found through calculation that the magnetic field of the Hybrid PMU structure can be increased by about 0.1T compared to the PPM structure with the same geometry.

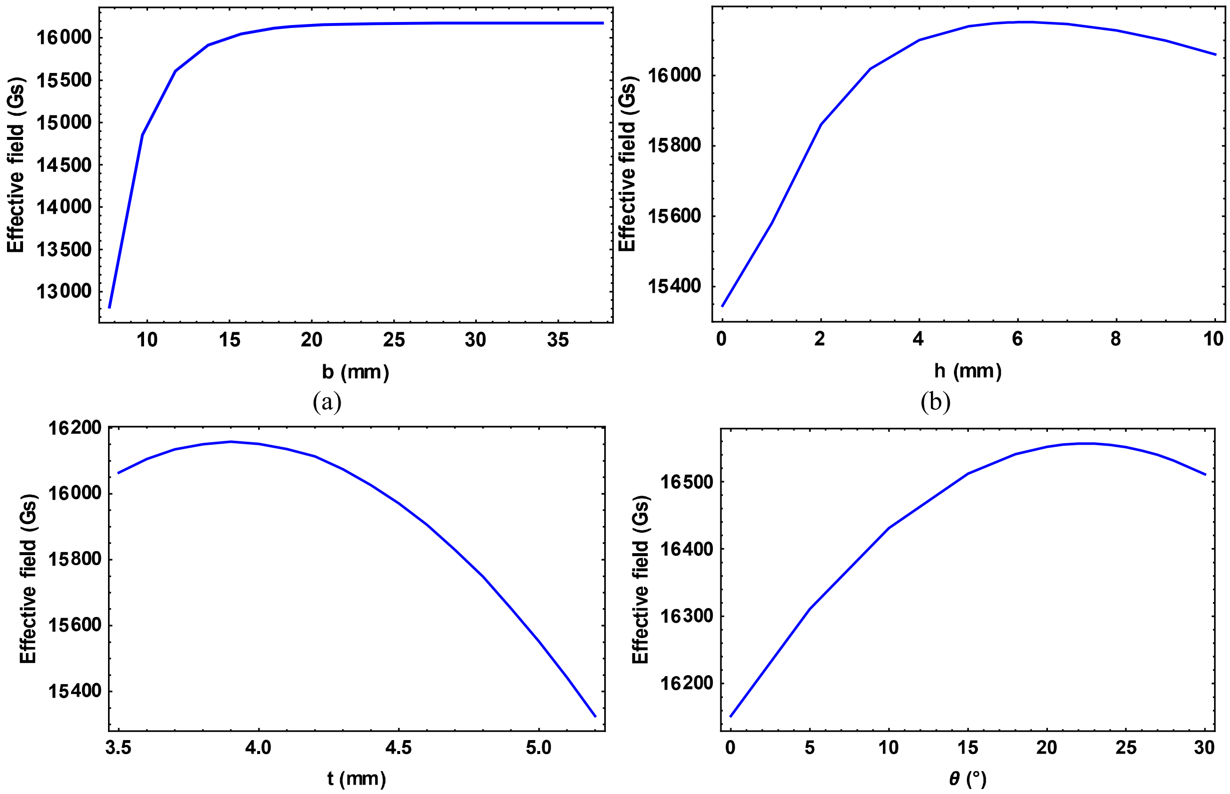


FIGURE 2. Variations of effective peak fields v.s. (a) the bevel of the side magnets, (b) the height of the pole, (c) the thickness of the H-Block and (d) the magnetization direction of the side magnets.

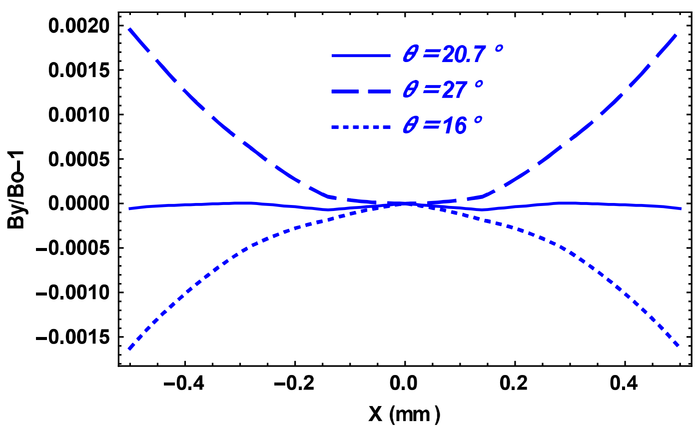
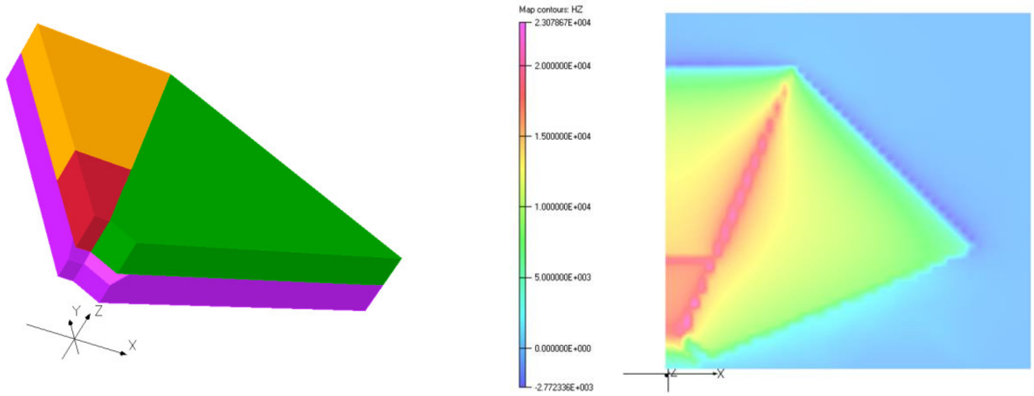


FIGURE 3. The roll-off of the peak field with different θ.

The magnets will be assembled at the room temperature and it is necessary to minimize the demagnetizing fields of the magnets. The simulation shows that, at the room temperature, the maximum demagnetizing fields inside the top magnets and the side magnets are less than 13 kOe. The maximum demagnetization field of about 27.4 kOe is inside the H-Block and is very close to the critical value 29.7 kOe of the magnet. To reduce the demagnetization field, a chamfer of 0.8 mm×0.8 mm is added to the bottom corner of the H-Bock as shown in Figure 4(a). Figure 4(b) shows the demagnetizing field distribution in the plane of z=1.94 mm which is inside the H-block and 0.01 mm deep to the interface of the H-block and the pole. With the chamfer, the maximum demagnetizing field in the H-block is reduced from 27.4 kOe to 23.1 kOe and the effective peak field of the undulator is lowered to about 1.63 T.



(a) (b)

FIGURE 4. (a) OPERA-3D model with the chamfer at the bottom corner of the H-Block and (b) The demagnetizing fields in the plane of z=1.94 mm at the room temperature.

MAGNET FIXTURE AND TUNING

Compared to the conventional hybrid PMU, the configuration of the novel undulator contains more types of the magnet blocks and the fixture of the magnets is more complicated. A new fixture will be considered as shown in Figure 5. Three grooves to fix the magnets are designed and the magnet shapes are also changed little. Two clamps are used to fix the side magnet blocks as there is a great magnetic force between the upper and lower magnet arrays. The peak field can be tuned by adjusting the height of the fixture.

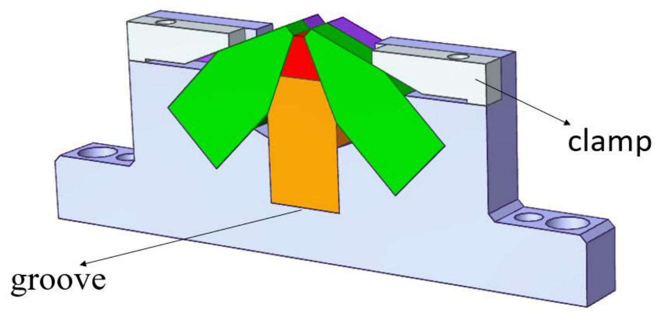


FIGURE 5. 3D view of the magnet fixture.

SUMMARY

A novel configuration of a hybrid PMU is presented. The simulated calculation shows that the effective peak field of 1.63 T is obtained at the gap of 4.2 mm for a NdFeB cryogenic permanent magnet undulator with the period length 16 mm and is at least 20% higher than the conventional hybrid PMU with the same ratio of gap to period length. The roll-off of the peak field is less than 1×10^{-4} within the good field region of ±0.5mm. The maximum demagnetizing field inside the magnet blocks is about 23.1 kOe and less than 80% of the critical value 29.7 kOe of the magnet.

REFERENCES

1. Hara T, Tanaka T, Kitamura H, et al., Physical Review Special Topics-Accelerators and Beams, 2004, 7(5):10-13.
2. http://www.sinap.cas.cn/
3. Zhou Qiaogen, Synchrotron Radiation News, 2018, 24(5):18-23.
4. K. Halbach, Nucl. Instr. Meth. 187 (1981) 109
5. Bahrdt J, Kuhn C., Synchrotron Radiation News, 2015, 28(3):9-14.