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OPTIMIZATION OF STAGGERED ARRAY UNDULATOR*

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Abstract

The staggered array undulator (SAU) consists of staggered poles and solenoid coils that form a periodically aligned transverse magnetic field in the pole gap. The addition of magnets in the longitudinal gap between the poles further enhances the peak field strength of the undulator. A method of enhancing the peak field strength of the undulator using cryogenic temperature permanent magnets and adding side magnets has been studied. The remanence of the magnet will increase at low temperatures and the peak field strength of the undulator will increase. The side magnets do not increase the maximum peak field strength of the undulator, but can reduce the solenoid magnetic field requirements and reduce the solenoid volume and cost. The influence of the special magnetic pole and magnet shape on the peak field strength of the undulator has also been studied.

INTRODUCTION

Short period is an important direction for the development of undulators, and it is an important and effective method for miniaturization of free electron lasers and obtaining short wavelengths [1]. By shortening the period of the undulator, a shorter undulator length can be obtained. According to the resonance relationship [2], a lower electron beam energy can be used for a given wavelength, which facilitates the miniaturization of free electron laser, or for a given energy beam, a shorter wavelength of radiation can be obtained. However, when the period of the conventional undulator is shortened, the undulator parameter is reduced as $K = 0.934B(\mathrm{T})\lambda_u(cm)$ [3]. In order to keep the undulator parameter *K* from decreasing as the undulator period is shortened, it is necessary to simultaneously enhance the field strength of the undulator. The staggered array undulator is a popular short period undulator scheme. The period of SAU can usually be very short, and the peak field strength can be very high. Its field strength is altered by changing the solenoid current. Large solenoid current makes the peak field of SAU be able to at or close to the maximum of the value physically allowed [4]. In the staggered array undulator of Sasaki *et al.*, the peak field strength of the undulator is enhanced by placing longitudinally magnetized magnets (M_z magnets) between the poles (Fig. 1) to avoid saturation in poles when the longitudinal field strength is large (>1.0 T) [5]. At cryogenic temperatures, the remanence of materials such as NdFeB and PrFeB can be increased by 20%, allowing the field strength of undulators to increase by more than 10% [6]. Based on this, we are exploring ways to increase the peak magnetic field strength of SAU, including cryogenic temperature and adding side magnets.

CRYOGENIC TEMPERATURE AND SIDE MAGNETS

The remanence of PrFeB can be increased to about 1.7 T at a low temperature of a few *K*. We determined the remanence as Br = 1.5 T, which is relatively easy to achieve.

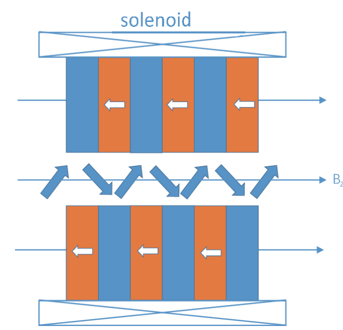

Figure 1: The structure of SAU. The magnetization direction of the magnet is opposite to the magnetic field of the solenoid.

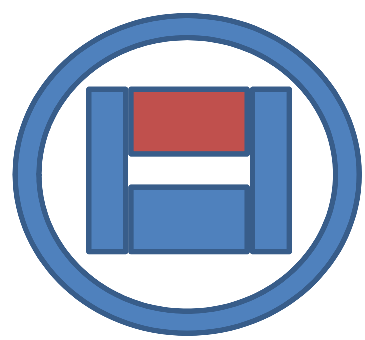

Figure 2: The structure of the cross section of SAU. The horizontal rectangles represent the magnetic pole and magnet of the SAU. The vertical rectangles represent the side magnets outside the SAU, whose magnetization direction is opossite to the solenoid. The outer ring represents the solenoid.

Figure 1 shows the structure of SAU. The cross section of SAU is shown in Fig 2. Side magnets are added to the outside of the SAU magnet and magnetic pole. The magnetization direction of the side magnets is opposite to that of the solenoid.

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Table 1: The Parameters of the SAU and Side Magnets

Parameter	Value
Size of magnets of SAU (x,y,z) /mm	(50,22,4)
Size of poles of SAU (x,y,z) /mm	(50,22,11)
Period /mm	15
N	10
Remanence B_r /T	1.25 or 1.5
Size of side magnets (x,y,z)/mm	(15,50,200)
Material of pole	CoFeV

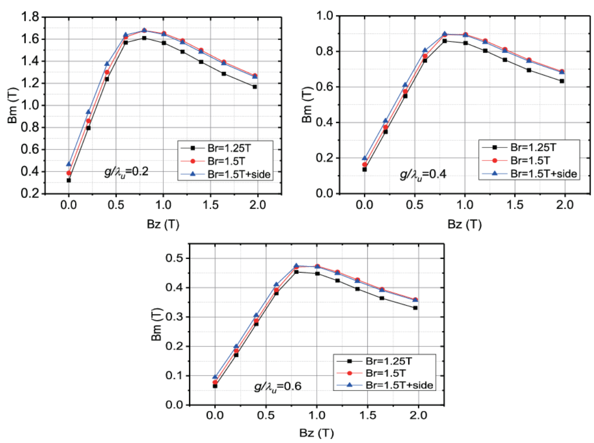

Figure 3: The peak magnetic field of SAU at different gaps. The curves with square remarks respect the peak field of SAU without side magnets and the B_r is only 1.25 T. The curves with circle remarks respect to that of the SAU with the B_r=1.5 T but no side magnets. The curves with triangle remarks respect the SAU with side magnets and B_r=1.5 T.

We designed an SAU with the parameters shown in Table 1. The peak magnetic field of SAU at different gaps are shown in Fig. 3. As the B_r is raised from 1.25 T to 1.5 T, the maximum of the peak magnetic field is enhanced simultaneously. To gain the same peak magnetic field with an SAU operated at cryogenic temperature, a smaller B_z of solenoid is needed. After adding the side magnets, the maximum value of the peak magnetic field strength does not increase. However, for the same peak field strength, the demand for B_z is also reduced. Increasing the magnetic field strength of a solenoid usually means a lot of volume and cost, hence, it is necessary to reduce the magnetic field strength requirement of the solenoid. The increase in the SAU peak magnetic field strength depends on whether the magnetic pole is saturated. When the magnetic pole is saturated, even if the longitudinal magnetic field in the undulator gap is increased, the peak field strength of the undulator will not increase. When the side magnets are added, the required solenoid magnetic field is smaller for the same peak magnetic field. However, after the saturation of the magnetic pole, the field strength of the undulator is not enhanced, so adding the side magnet does not increase the maximum value of the peak field strength.

SPECIAL POLE STRUCTURE

Adjusting the magnetic pole structure can adjust its ability to concentrate magnetic lines. We adjusted the structure of the magnetic pole and studied its effect on the peak field strength of the undulator.

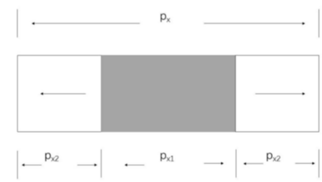

Figure 4: The transverse structure of the pole. The middle part is still CoFeV, and the ends are changed to magnets with different magnetization directions.

Figure 4 is a schematic view of the transverse structure of the pole. We change the width of the center pole by adjusting the size of p_{x1}.

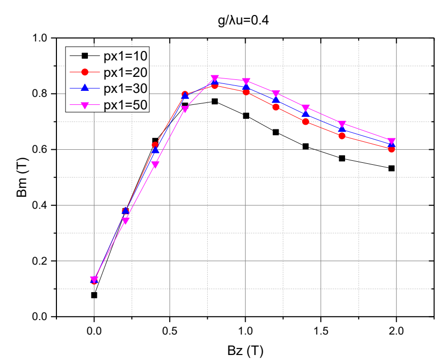

Figure 5: Peak magnetic field at different p_{x1}.

Figure 5 shows the change of peak magnetic field of SAU while changing the p_{x1} of poles, while B_r=1.25 T. It is shown that while the width of center part of the pole (CoFeV) is reduced, the peak field strength will be reduced simultaneously. This adjustment of the magnetic pole structure does not enhance the peak field strength of the undulator.

CONCLUSION

The use of cryogenic temperature technology and the addition of side magnets all reduce the SAU's requirements for the magnetic field of solenoid. Also, the peak magnetic field strength of the SAU is improved when operating at low temperatures.

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