THE POSSIBILITY FOR A SHORT-PERIOD HYBRID STAGGERED UNDULATOR

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Abstract

A short-period hybrid-type staggered undulator is proposed. A proper combination of vanadium Permendur (VP) pole and NdFeB magnet provide approximately 40% larger peak field strength than a conventional staggered undulator. The peak field of a 15-mm-period hybrid staggered undulator exceeds 0.8 T at a gap of 6 mm. Also, by using dysprosium as a pole and PrFeB as a magnet at liquid nitrogen temperature (77K), even higher peak field (~0.94 T) can be achieved at the same gap.

INTRODUCTION

After pioneering work to develop a superconducting undulator (SCU) for a free-electron laser (FEL) at Brookhaven National Laboratory, much R&D of SCUs is underway in various laboratories [1-5]. Short-period SCUs will give a wide range of opportunities for research in the synchrotron radiation sciences. However some technical challenges exist, such as beam and/or radiation heating of the vacuum chamber.

Recently, SPring-8 started to develop a short-period permanent-magnet cryogenic undulator [6]. By taking advantage of higher remanent field and higher coercivity at lower temperature, they are planning to use permanent magnets (NdFeB or PrFeB) for an in-vacuum undulator at 150K or 77K. The achievable maximum field of such a device is smaller than that of an SCU at the same gap. However, due to the nature of an in-vacuum undulator (no vacuum chamber wall between the electron beam and an undulator magnet), the achievable minimum gap can be smaller than that of an SCU.

A third possibility for a short-period undulator is a staggered undulator. The staggered undulator was constructed for an FEL experiment more than a decade ago [7]. It consists of a solenoid and poles made of high-permeability material. The poles are aligned in a staggered way so that the solenoid field wiggles, and hence a sinusoidal transverse-field component appears on the undulator axis. The problem with this type of device is that achievable maximum field is smaller than that of a permanent magnet undulator.

In this paper, a hybrid staggered undulator is proposed. It consists of a solenoid, poles and magnets. With this newly proposed structure, the maximum field can be much higher than that of a conventional undulator.

MAGNETIC DESIGN AND PERFORMANCE

Figure 1 shows a drawing of the proposed structure for a hybrid staggered undulator. One difference from the original staggered undulator is the insertion of magnet blocks between the poles. The direction of magnetization of each magnet should be reversed compared to the direction of solenoid field, as shown with a solid black arrow in each magnet.

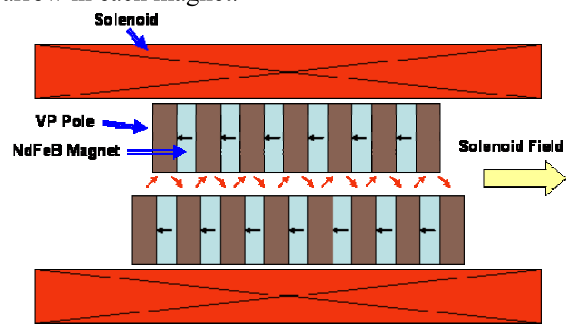

Figure 1: Schematic of a hybrid staggered undulator.

Also in this figure, small arrows in the gap represent the wiggled solenoid field induced by high-permeability poles and magnets. Figure 2 shows the peak vertical-field component as a function of the longitudinal solenoid field. The calculation was done by assuming a pole length of 8.5 mm, a magnet length of 6.5 mm, hence a period length of 15 mm and a fixed gap of 6 mm. The pole material was assumed to be vanadium Permendur (VP), and the magnet was NdFeB with a remanent field of 1.25 T.

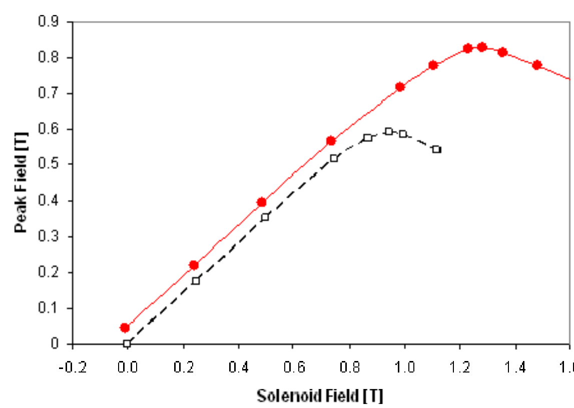

Figure 2: Vertical peak field variation as a function of the longitudinal solenoid field. The solid curve with solid circles represents the peak field variation of the hybrid staggered undulator, and the broken curve with open squares represents the field variation of a conventional staggered undulator.

In each curve, there is a maximum at a certain value of solenoid field due to the saturation of magnetization in the pole material. The achievable maximum fields are 0.83 T at a 1.28 T solenoid field for a hybrid staggered undulator and 0.59 T at a 0.94 T solenoid field for a conventional structure, respectively. Field calculations were done by using RADIA [8]. Figure 3 shows the expected tuning curves of brilliance from a 15-mm-period hybrid staggered undulator. The calculation used XOP [9] and assumed an undulator length of 1.2 m (N=80). Also, the most recent beam parameters for the APS storage ring were assumed. The maximum brilliance at a photon energy of 18.4 keV is obtained at the minimum gap (6 mm).

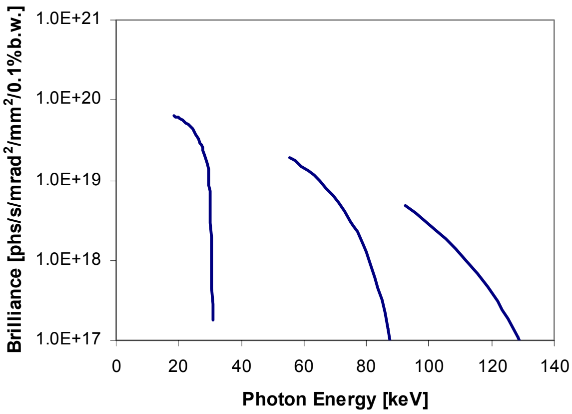

Figure 3: Tuning curves of peak brilliance from a 15-mm-period hybrid staggered undulator. Electron energy: 7 GeV, emittance: 2.5 nmrad, coupling: 1%.

TILTED CONFIGURATION FOR ELLIPTICAL POLARIZATION

Similar to the tilted superconducting undulator for generating elliptically polarized radiation [10-12], a tilted hybrid staggered undulator scheme also works as an elliptical undulator. Rotating the poles and magnets in the horizontal plane in opposite directions for the top and bottom arrays, as shown in Fig. 4, produces a horizontal-field component, at the cost of vertical-field reduction.

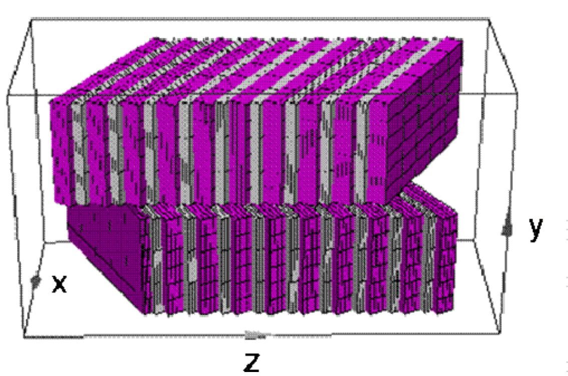

Figure 4: Schematic drawing of the tilted configuration. Thick blocks and thin blocks represent VP poles and magnets, respectively.

Figure 5 shows the vertical and horizontal peak-field variation as a function of tilting angle from the x-axis. The horizontal field has a maximum at around the 30 degrees. In order to keep the same period length, the pole and magnet dimensions in the z-direction were changed as a function of tilting angle, but other dimensions were kept constant. The magnetic performance of this device is about 60% higher than the staggered undulator described in ref. 12 at the tilting angle of 30 degrees.

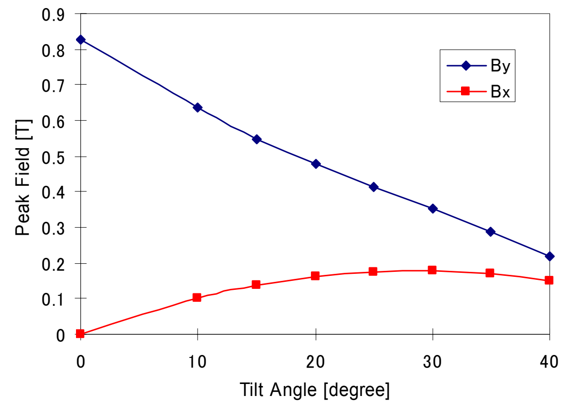

Figure 5: Horizontal-field B_x (square) and vertical-field B_y (diamond) variation as a function of tilting angle at a gap of 6 mm. The period length was kept constant at 15 mm. Constant solenoid field (1.28 T) was assumed.

Figure 6 shows the brilliance spectrum from a tilted hybrid staggered undulator at a gap of 6 mm. The tilt angle was assumed to be 30 degrees for the calculation.

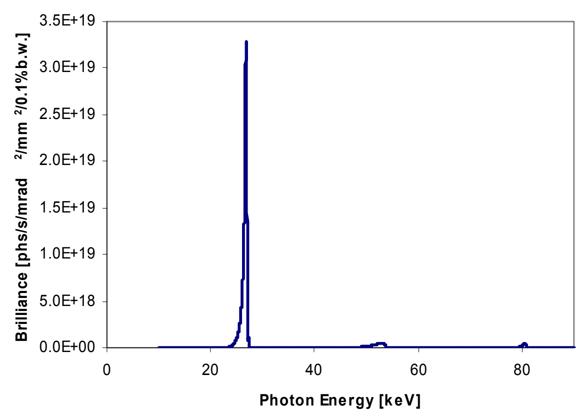

Figure 6: Brilliance from a 15-mm-period tilted hybrid staggered undulator. The calculation was done by using XOP [9].

The degree of circular polarization was 82% at the peak.

COMPARISONS WITH OTHER DEVICES

Figure 7 shows the gap dependence of the peak field for several different undulators with a 15 mm period length. The highest performance is given by a superconducting undulator (dashed curve). This curve was calculated by assuming the dimensions of a SCU designed at the Advanced Photon Source [3]. The lowest curve represents a conventional staggered undulator with VP poles (solid curve with crossed markers). The curve with circle markers represents the performance of a

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conventional hybrid-type permanent-magnet undulator that is similar to a standard undulator at the Advanced Photon Source. The curve with triangles is the peak-field variation of the hybrid staggered undulator that is proposed in this paper, and the curve with squares is that of a cryogenic (77K) hybrid staggered undulator with dysprosium poles and PrFeB magnets with a remanent field of 1.5 T. These materials were suggested for a cryogenic undulator in ref. 6.

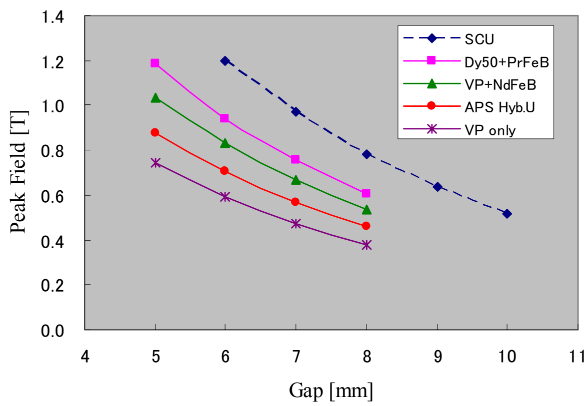

Figure 7: Peak field as a function of gap for various devices.

It is obvious that the SCU gives the best performance as a short-period undulator. However, there are challenges remaining for SCUs, such as quenching problems due to image current or radiation heating, magnetic-field measurements and field-error compensation at liquid helium temperature. Also, constant consumption of liquid helium may cause a high running cost.

On the other hand, a simple-structured hybrid staggered undulator at a room temperature has no such problems, though the achievable maximum field is about 69% that of an SCU at the same gap. A potential problem of this type of device is the effect of the longitudinal solenoid field on the electron beam. However, this problem may be solved by adding compensation coils at both ends of the main solenoid [13].

CONCLUSIONS

A short-period hybrid staggered undulator is proposed. This simply structured device has a higher performance level than that of a conventional staggered undulator or a hybrid permanent-magnet undulator. The hybrid staggered undulator requires neither gap control for changing the strength of the magnetic field nor a cryogenic environment near liquid-helium temperature. This feature may be an advantage to reduce technical difficulties and cost.

ACKNOWLEDGMENTS

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