MAGNETIC DESIGN FOR A STAGGERED HYBRID UNDULATOR

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Abstract

A superconducting solenoid along with staggered hybrid magnetic array scheme was investigated for short period undulator designs. In the staggered hybrid magnetic array, the permanent magnet blocks placed between the vanadium permendur pole are arranged to enhance the alternating vertical magnetic field strength. According to the field calculation, the solenoid field achieves a significantly high vertical magnetic field of 1.36 T and a longitudinal magnetic field of 1.1 T for the 10-mm length undulator at a 2-mm gap width. The vertical field strength of 1.39 T was measured at 2-mm gap on a 3-period mockup. Furthermore, the longitudinal and vertical magnetic field uniformity of the end magnetic structures was designed to satisfy the stringent magnetic field requirements and to increase the effectiveness of the magnetic poles.

1 INTRODUCTION

In a given particle beam, a short-period undulator can produce higher energy photons. Recently, considerable new short period devices were studied notably. At NSLS an 11-mm period undulator with magnetic field of 0.7 T can operate with a magnetic gap as low as 3.3-mm [1]. Another staggered array wiggler, a 1.08 T peak wiggler field, was measured for a 2-mm gap in a 10 mm-period [2]. On a new device, the superconducting undulator with 3.8-mm period length has been tested at FZK Karlsruhe [3].

Generally, a higher field is difficult to create with a short period undulator. The achievable field decreases as the ratio of period/gap reduces. A peak field was limited to approximately 1 T at a 2-mm gap in a 10-mm period undulator. To maintain a reasonable gap and tuneability of the photon energy, it is necessary to enhance the magnetic field strength. Therefore, one of most significant goals is the development of a high magnetic field undulator. This work describes the design of a 10-mm period staggered hybrid undulator and the its field analysis.

2 MAGNETIC STRUCTURE DESIGN

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A Halbach-type hybrid magnetic structure was the most popular undulator. The magnetic field of this undulator depends upon the characteristics of the permanent magnet as well as the saturation field of the ferromagnetic pole. However, in a short period magnet array, the achievable field is limited through the ratio between magnetic block thickness and period. We investigated that the highly permeable material, which could produce higher longitudinal magnetic field strength over the entire undulator via a solenoid field, could replace the magnet blocks with the same magnetism direction. These magnetic fields increase the magnetic flux being generated into the pole-pieces until the pole reaches saturation. Hence, the staggered hybrid undulator achieves a higher magnetic field, as in a Halbach hybrid structure undulator. To realize a high magnetic field, we employed a staggered hybrid undulator and examined how its enhancement of the magnetic field in a short period undulator.

Figure 1 illustrates a configuration of a staggered hybrid undulator. The alternating sinusoidal field was derived from a staggered hybrid magnetic array inside a solenoid coil. The pole blocks are manufactured by the vanadium permendur. Owing to the high permeability of the vanadium permendur pole, the solenoid field is deflected vertically into each vanadium permendur face to form an alternating vertical field, while providing a longitudinal field on the axis. In a staggered hybrid array, to enhance the magnetic field, the permanent magnet blocks placed between the vanadium permendur pole are arranged to increase the alternating vertical magnetic field strength.

Three-dimensional field analysis optimized the permanent magnet and pole parameters. Magnetic field calculations were performed with TOSCA/OPERA-3D computed code [4]. In this calculation, the permanent magnet was Nd-Fe-B. The ratio of magnet block to undulator period, f, was 0.4, which is the value that maximizes the vertical field for the specified gap width and a 10-mm undulator period. Furthermore, a wedge pole was designed to achieve higher field strength.

The given longitudinal field varied the vertical field strengths. Figure 2 plots the current density of solenoid coil versus longitudinal and vertical fields to optimize the vertical field design. In the magnet design procedure, damage to the magnet blocks can occur during the largest reverse solenoid field. The permanent magnet could not exceed –1.25 Hc to rely on reproducible magnet operation.

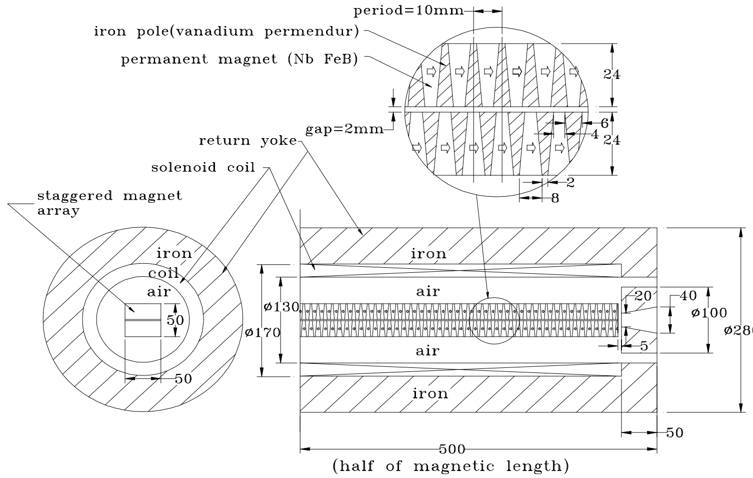

Figure1: The configuration of the staggered hybrid undulator.

According to the field calculation, a significantly high vertical magnetic field of 1.36 T and a longitudinal magnetic field of 1.1 T are achieved by the solenoid field for the 10-mm period length undulator at 2-mm gap width. The field uniformity within 0.1 % in transverse axis extend to 30 mm due to strongly saturated pole at pole width of 50 mm. Regarding field intensity and uniformity across the center of the transverse plane, a staggered hybrid undulator is superior to a staggered array without a permanent magnet.

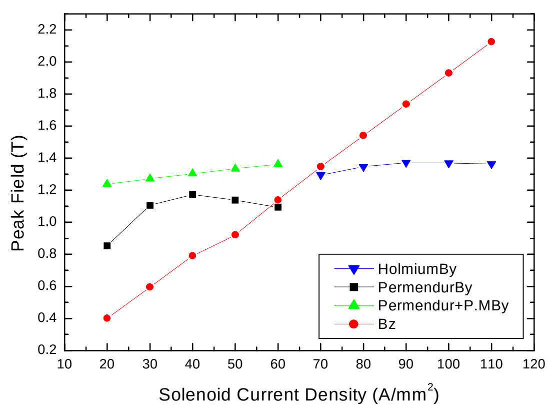

Figure 2: The current density of solenoid coil versus longitudinal and vertical fields with different pole material.

At a low temperature of 4.2 K, the holmium has an exceptionally high saturation value of roughly 4 T. At fields exceeding 2.5 T, the permeability of holmium is greater than that of vanadium permendur. Holmium has the highest saturation and was therefore used to achieve maximum performance. The highest vertical field of 1.372 T can be achieved during a given solenoid field at 1.736 T. Regardless, the vertical field strength is not significantly increased through the use of holmium. Figure 3 indicated the vertical and longitudinal field strength functions of various gaps with the hybrid structure, the holmium pole and the vanadium permendur pole. A further increase of vertical field up to 16 % could be achieved by the hybrid structure.

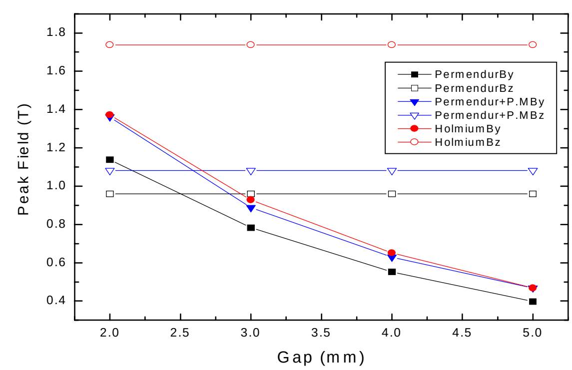

Figure 3: The vertical and longitudinal field strength functions of various gaps with the hybrid structure, the holmium pole and the vanadium permendur pole.

The calculated field strength and the field performance were examined by a 3-period mockup by using the conventional NdFeB magnet blocks and the vanadium permendur pole. A standard magnet for the Hall probe and the NMR field calibration was used to transform the longitudinal field into the solenoid field. The electrical magnet could provide the field strength of 1.8 T with 0.01 % uniformity in 48-mm gap width. The 3-period mockup was assembled without using the wedge pole from the existing material. To avert the irreversible demagnetization of the permanent magnet, the solenoid fields could not be operated at a field strength exceeding 0.8 T. Figure 4 indicates the measured longitudinal field profiles at 2-3 mm gap. The measured vertical peak field was 1.39 T at longitudinal field of 0.678 T, as predicted by the field design.

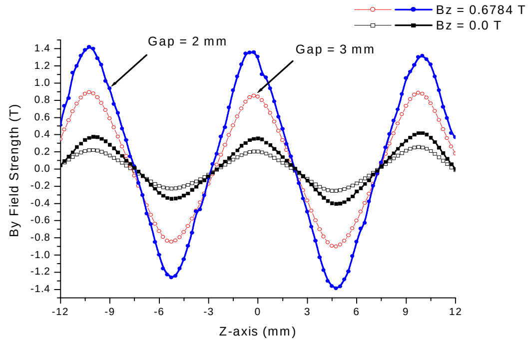

Figure 4: The measured longitudinal field profiles at 2-3 mm gap.

3 END POLE STRUCTURE DESIGN

To increase the effective magnetic poles the vertical, longitudinal magnetic field uniformity must satisfy the stringent magnetic field requirements. Figure 1 indicates the half section of a staggered hybrid undulator. After removal of staggered array, the longitudinal field, which remained uniform within 0.1 %, is approximately 0.6 m within the middle of 1 m long solenoid coil. Furthermore, two 50 mm long with 1 mm thick trim coils at both ends were used to extend the uniform range, which could extend to 0.8 m. In addition, the superconducting solenoid with an iron return yoke and a vanadium permemdur end pole were designed to increase the effective magnetic length up to 0.85 m.

Electron trajectory walk-off may be corrected by an appropriate design of an adiabatic section at both ends of an undulator. Our design has an even number of poles which to produce an anti-symmetric field. The anti-symmetric field configuration automatically cancels any unanticipated systematic multipoles present in the end fields, leaving only the random components to be corrected. Figure 1 indicates the proposed end pole configurations. The end field analysis was predicted by two dimensional calculation approaches, which in turn determined the end pole geometry. To adjust the field distributions, the magnet blocks in the end pole were partially reduced. Figure 5 displays the calculated vertical and longitudinal field distributions of the end region.

4 TECHNICAL LAYOUT

The staggered hybrid array undulator has several advantages: producing higher energy photons, a high field is attainable at short periods, wavelength tuning is available by varying the solenoid field, and low random field errors is achievable at a fixed gap width [2]. The good field region within 10-mm is required in transverse axis. For extending a wider first harmonic photon range, a solenoid coil can facilitate three magnet arrays with distinct periodic length in diameter of 100 mm. The undulator is 1.3 m in length and has a 2-5 mm gap. Using a Hall probe within such a limited gap, it is difficult to measure the 3-dimensional magnetic field with great accuracy. To verify and correct the field distortion caused by the magnet blocks and mechanical gap errors, the field errors of half of a magnetic structure assembly can be measured initially by the Hall probe measurement system. Finally, the field uniformity has been measured with the pulse-wire techniques. Furthermore, within the gap, an intrinsic large vertical field gradient occurred. Undulator alignment will seriously affect the electron trajectory. Four steering magnets are installed to control the electron trajectory.

5 CONCLUSIONS

A short-period staggered hybrid undulator was designed by optimizing its magnet and pole parameters. A further increase of vertical field up to 16 % could be achieved by the given solenoid field for the 10-mm period length undulator at 2 mm gap. The measured field strength was 1.39 T with a vanadium permendur pole and permanent blocks on a 3 periods mock-up at 2 mm gap. Herein, the vertical magnetic field uniformity in the transverse and the longitudinal directions are designed to satisfy the stringent magnetic field requirements. We predict that the end magnetic structures will increase the effective magnetic length up to 0.85 m.

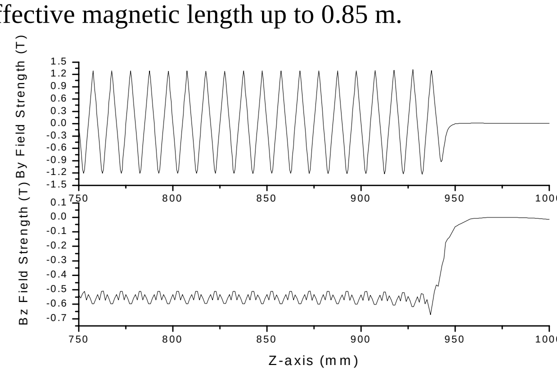

Figure 5: The calculated vertical and longitudinal field distributions of the end region.

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