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DESIGN OF A DELTA-TYPE SUPERCONDUCTING UNDULATOR AT THE IHEP

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Abstract

Undulators play an important role in the 4th generation radiation light source. In order to satisfy different requirements of the experiments, various undulator structures have been proposed. The Delta-type undulator can provide circular polarized radiation. Conventional undulators are usually made of permanent magnets, but the application of the superconducting technology in the undulator is developing quickly. Compared to the permanent magnet undulators, superconducting undulators can provide higher photon flux with the same magnetic pole gap and period length, especially when the period length is longer than 20 mm. An R&D project is underway to produce a prototype of a Delta-type superconducting undulator with 28 mm long period and 12 mm gap at the IHEP. The structure design and the simulation results of the magnetic field are presented in this paper.

INTRODUCTION

Synchrotron light sources as storage rings and free electron lasers (FELs) employ undulators to produce high brilliance photon beams [1]. At present most of the undulators are made of permanent magnets. But the superconducting undulators can produce larger peak magnetic fields on axis for the same gap and thereby increase the spectral range of the emitted photons [2]. Therefore, the interests and effort in developing the superconducting undulators (SCUs) have grown around the world. A superconducting magnet is constructed with coils made of superconducting materials wound around the ferromagnetic cores. Recently SCUs have successfully operated in the Karlsruhe Institute of Technology (KIT) synchrotron and the Advanced Photon Source (APS) at the Argonne National Laboratory (ANL) [3, 4].

At the Institute of the High Energy Physics (IHEP) in China, a research group have been formed to study the SCUs. The SC magnets are arranged periodically and the coils are operated with alternating current pattern to create an undulatory magnetic field on axis. The field strength can be controlled by the current density. In addition to the planar-type SCUs, we also have R&D projects to study the variably polarizing undulators which can provide not only the linear polarization but also the circular or the elliptical polarization radiation. In this paper, we propose a Delta-type SCU, which has a similar structure to the Delta-type permanent magnet undulator [5].

The IHEP insertion device (ID) group plans to build a prototype of a 0.5 m long Delta-type SCU device. The initial phase of the R&D project includes the intensive magnetic modeling performed with the OPERA-3D and the RADIA software packages [6, 7]. The simulation focuses on the magnetic design of the SCU including calculation of the peak field on the axis and the maximum field in the coils, superconductor load line optimization and the undulator correction coils. The characterizations of the magnetic field of the Delta-type SCU are presented in the following sections.

DELTA SCU STRUCTURE

The Delat-type SCU consists of four superconducting magnet arrays symmetrically arranged around the beam axis, as shown in Fig. 1. The green parts are iron cores and the red parts are coils wound on the cores. The coils are made of superconducting NbTi wire with a circular cross section of 0.6 mm diameter. The current direction is inverted for the adjacent coils in the same array. The vertical magnet arrays are displaced by 1/4 of a period relative to the horizontal arrays in positive z-direction resulting a 90° shift in phase between the vertical and horizontal field components. The gap between the opposite poles is 12 mm and the period of the SCU is 28 mm. Some designed parameters of the Delta-type SCU are listed in Table 1.

The vertical and horizontal magnetic field components on the axis are controlled by the current in the vertical and

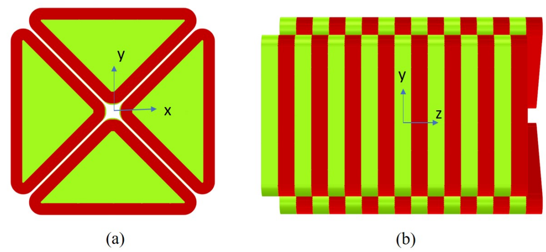

Figure 1: Delta SCU cross-section (a) and side view (b).

Table 1: Delta-type SCU Parameters

Parameters	Values
Undulator length	~0.5 m
Gap	12 mm
Period	28 mm
Coil Groove	6 mm × 7 mm
Peak field	≥1T

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horizontal coil array respectively. By varying the current or direction in the coil arrays, the radiation Stokes parameters can be changed and thus one can obtain different polarized photon beams on the axis. Figure 2 presents some typical polarization modes including circular polarization, elliptical polarization and linear polarization. In this paper, the computation of the Delta-type SCU focus on the circular and linear polarization modes.

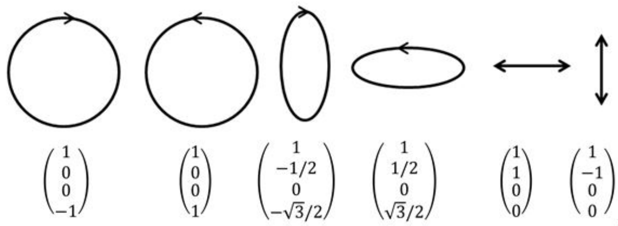

Figure 2: Some typical polarization types with the corresponding Stokes parameters that can be provided by Delta-type SCU.

COMPUTATION RESULTS

The physical calculation of the Delta-type SCU is performed in 3D magnetic models using numerical calculation software packages such as OPERR-3D and RADIA. In the simulation, the Delta-type SCU model has 36 poles and 35 coils for each magnetic array with 12 mm gap and 28 mm period. The corss-section of the coil groove region is 6 mm × 7 mm. The results of the magnetic fields calculation are presented in this section.

Load Line Calculation

The load line for the superconductor in the Delta-type SCU is calculated based on the fitting function of NbTi superconducting wire. The critical current in the NbTi wire is dependent on the temperature and the magnetic field strength. The SCU is operated at a temperature of 4.2 K and the maximum magnetic field on the wire is obtained via the numerical calculation.

The calculated load line for the Delta-type SCU is shown in Fig. 3. The undulator magnetic field strength on the axis increases with the increase of the applied current density, while the critical current density in the NbTi wire decreases. The critical current density for the Delta-type SCU is about 1340 A/mm^2. In order to reach the 1 T undualtor peak field, the applied current density should larger than 1100 A/mm^2, about 82% of the critical value.

Magnetic Field

For the circular polarization mode, the current in the coils has the same magnitude but different direction for the adjacent coils and the opposite coils. The magnetic field distribution on axis at the operation current (1100 A/mm^2) for the circular polarization mode is plotted in Fig. 4. The horizontal component (B_x) and the vertical component (B_y) of the magnetic field are the same but shifted in a phase of $\pi/2$.

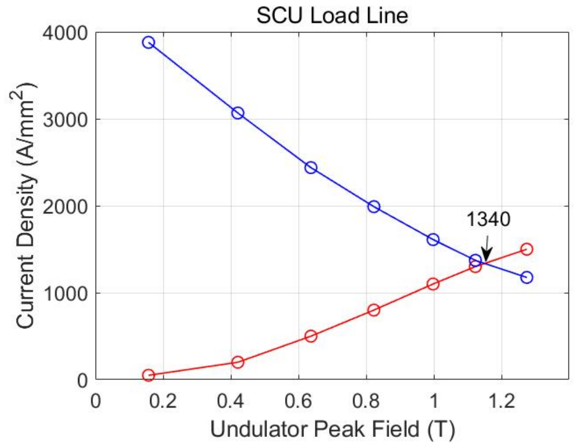

Figure 3: Load line for the Delta-type SCU.

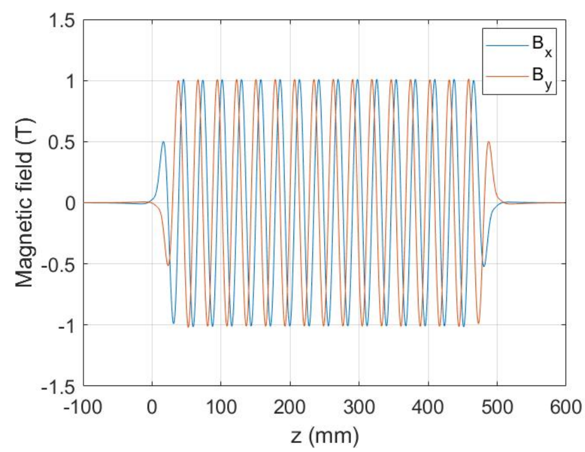

Figure 4: Magnetic field distribution on axis for the circular polarization mode.

If the current in the horizontal or vertical coils is zero, the Delta-type SCU then turns into a planar undulator and generates linear polarization magnetic field. Figure 5 shows the vertical linear polarization mode. The current density in the vertical coils is 1100 A/mm^2 and is zero in the horizontal coils. The vertical component of the magnetic field B_y becomes slightly less than 1 T and the horizontal component is not zero, which means the vertical coils can contribute the horizontal magnetic field component on the axis and the horizontal coils can contribute the vertical magnetic field component.

Correction Coils

The second integral of the magnetic field is dependent on the relative strength of the first few poles on each end of the undulator. In order to minimize the final second field integral, permanent magnet undulators usually provide end-field correction by decreasing the strength of the magnets on both end jaws. In the case of SCU, correction coils are wound on the two end grooves of both ends of the iron cores along with the main coils to provide the required end fields. The schematic drawing of the correction coils in two grooves

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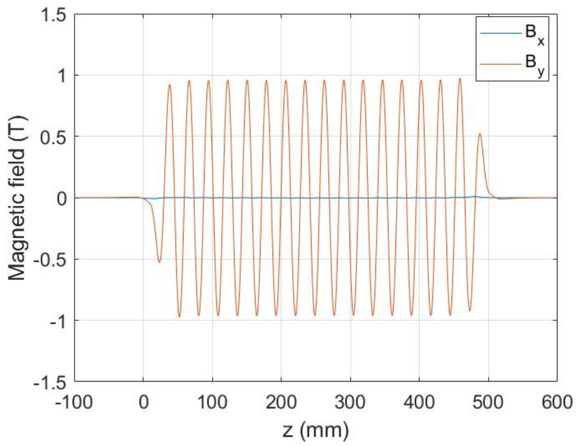

Figure 5: Magnetic field distribution on axis for the vertical lienar polarization mode.

on one end of a core is shown in Fig. 6. The red parts stand for the main coils and the yellow parts for the correction coils. The first correction coil part (C1) occupies 3/4 of the groove region and the second correction coil part (C2) occupies 1/4 region.

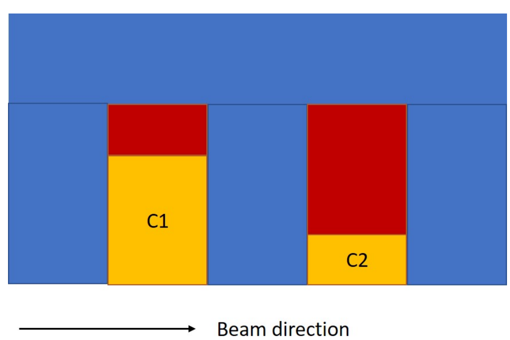

Figure 6: Schematic drawing of the correction coils.

By applying different current density in the correction coils, the second integral of the magnetic field can be changed. Figure 7 shows the second integral of the horizontal field component and the vertical field component with different correction current density. The trend of the second integral of the horizontal and vertical magnetic field as the correction current density is not the same. Further studies are needed to figure out the optimized correction current.

SUMMARY

An R&D project is undergoing at the IHEP aiming to build a prototype of a Delta-type SCU. In this paper, we introduce the primary design of the Delta-type SCU containing the magnetic field calculation by using OPERA-3D and RADIA software packages. The Delta-type SCU can generate circular and linear polarization photon beams. In order to reach the designed magnetic peak field (1 T) on axis, at least a current density of 1100 A/mm^2 is required. Correction coils are applied on both ends of each core to adjust the end fields. The second integral of the magnetic fields with different correction current are also calculated. Further studies for the Delta-type SCU are required to optimize the physical parameters.

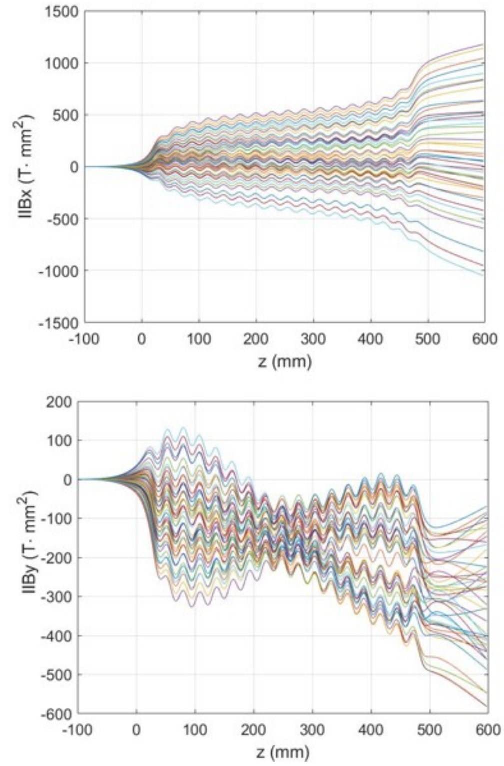

Figure 7: Second integral of the horizontal (top) and vertical (bottom) magnetic field component with different current density.

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