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A SUPERCONDUCTING UNDULATOR WITH VARIABLE POLARIZATION DIRECTION FOR THE EUROPEAN FEL

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Abstract

In the SASE3 beam line at the European XFEL a planar undulator produces linearly polarized radiation. In order to obtain a circularly polarized radiation an afterburner will be installed to produce coherent radiation with variable polarization. Recently Argonne National Lab developed a super conductive undulator (called SCAPE) for a storage ring which allows to change polarization direction and field strength without moving mechanically the undulator parts. In this paper it is investigated if a similar device could be useful for an FEL. Such device is also a possible choice for the future undulator beam lines where circular and variable polarization are required.

INTRODUCTION

The magnetic field for undulators is in general produced by permanent magnets at room temperature. During the last years experiments were performed to increase the magnetic field either by cooling the permanent magnets to cryogenic temperatures [1] or by replacing the permanent magnets by superconducting wires.

The magnetic field of cryogenically cooled permanent magnets (CPMUs: cryogenic permanent magnet undulator) is in general higher by only about 15 % but the magnets are less sensitive to radiation. The disadvantage is that the frequency and the polarization of the emitted radiation have to be changed by moving mechanically the undulators gap.

Undulators with superconducting wires (SCU) can produce up to a factor of two higher undulator fields compared with cryogenic undulators and are also almost insensitive to radiation. The SCU technology has in addition the advantage that it is possible to tune the output frequency and the polarization direction electrically without mechanically moving the magnet coils. The disadvantage is that liquid Helium is needed to cool the coils. This problem was recently reduced by using cryocooler. The cryocooler, mechanically attached to the undulator, has a closed helium system. Undulator and cooler together comprise a standalone unit and require therefore not a conventional cryoplant. The cooling time for such a system is about 70 hours. APS and KIT both used such undulators successfully. The advantage is the tunability of the frequency of the produced radiation.

Recently a NbTi undulator was proposed by the Argonne group (SCAPE: Super Conducting Arbitrary Polarization Emitter) [2] was proposed to build an undulator with electrically adjustable photon wavelength and polarization.

The winding technics with NbTi superconducting wires lead to low phase errors (less than 3 degree) and therefore shimming is not required. NbTi wires are at the moment the used for SCUs. Nb_3Sn wires can produce in general higher fields but are at the moment still difficult to handle. The use of high temperature superconductors are investigated at various institutes.

In this paper first ideas on a program on the development and tests SCUs with the parameters for the European XFEL are presented.

PLANAR SCU

A SCU with the period of 18mm can serve for an ultra-high photon energy SASE beam line up to 100keV at the European XFEL. It also applies the factor of 1.5 to the tenability of the photon energy [3]. Therefore in this section we focus on the field simulations for an 18mm period planar SCU, U18.

Both of the successful examples of planar SCU from APS and KIT take use of so called the vertical winding technique for the magnet coils. It is winding the superconducting coil continuously on a block of iron core with grooves. In this paper we follow it for the undulator design and simulations.

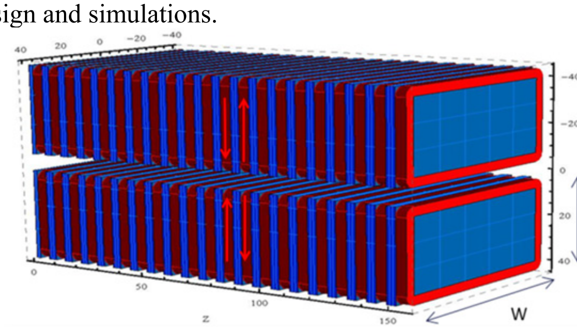

Figure 1: The radia model for the planar SCU.

Figure 1 shows the Radia [4] model for the planar SCU U18. The red coil indicates the NbTi wire and the blue part is the iron core for the wire winding and poles assembling. The arrows indicate the current direction. The wire material is supposed to be NbTi and the iron core is supposed to be normal low carbon steel.

In order to simulate the maximum undulator field it is firstly needed to evaluate the critical current density. It is well known that the superconducting condition is maintained by the nonlinear relations of the temperature, the magnetic field and the current density. We assume the undulator wire is constant in the temperature of the liquid helium which is 4.2K. Following the suggestion of Ref. [5] the critical current density is assumed linearly relates to the magnet field:

$$j_c = j_a\left(1 - \frac{B_m}{B_{c2}}\right), \quad (1)$$

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where j_c is the critical current density and B_m is the magnet field at the wires. $j_a = 2.1kA/mm^2$ and $B_{c2} = 10.4T$ are the parameters for the superconducting conditions of NbTi. It is seen that the higher the magnet field the lower the maximum current density that the superconducting wire can take.

Figure 2 shows the simulation results for the undulator peak field and the critical current density with respect to the applied current density in the undulator wire. It is seen that as the applied current density increasing the undulator peak field goes up but on the contrary the critical current density goes down. The maximum undulator field is given at the point where the applied current density equals to the critical current density, i.e. the maximum current density the wire can take with the super conducting condition is kept. According to the simulations shown in Fig. 2 the critical current density is 1270A/mm^2 and the maximum peak field is 0.97T.

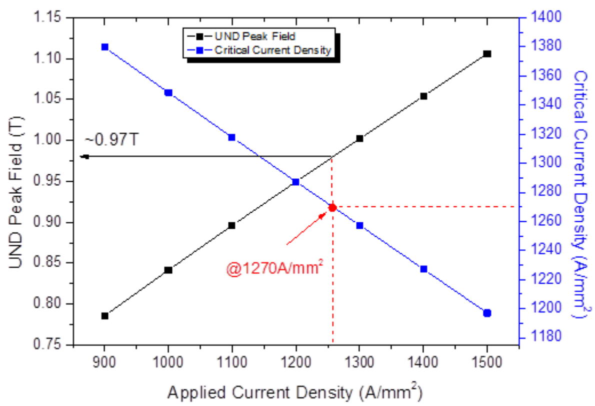

Figure 2: The undulator peak field and the critical current density with respect to the applied current density.

The smaller undulator field can be continuously achieved by reducing the current density. We summarize the parameters of U18 in the Table 1.

Table 1: Parameters for U18

Parameter	Unit	Unit
Period λ_u	18	mm
Coil cross section	5×5	mm
Iron core size W&H	80&40	mm
Pole width	4	mm
Gap g	10	mm
Max. current density	1270	A/mm^2
Max. peak field	0.97	T
Max. K parameter	1.63	--
Long. λ_r @17.5GeV	0.18	Å

HELICAL SCU

The planar undulator only generates the linear polarization SASE, to some users especially to the soft X-ray users the circular and the adjustable polarization is needed. In the European XFEL the permanent helical undulator APPLE-X will be built as the after burner in the soft X-ray beam line SASE3 [6, 7]. In this paper a similar type of APPLE-X undulator in the super conducting version is simulated. Such a superconducting helical undulator is developed in Argonne lab in the name of SCAPE undulator [2].

The Radia model for a helical super conducting undulator is shown in Fig. 3. It is comprised with four magnet arrays whose cross section is triangle. The pair of horizontal arrays generates the horizontal field and the pair of vertical arrays is for the the vertical field. The red coils indicate the NbTi coil and the blue part indicates the iron core and poles. A round vacuum chamber can be placed in the middle of the undualtor for the beams. Such a undulator is suitable for the small beam size in both horizontal and vertical plane, which is the case in the XFEL facilities and the diffraction-limited SR sources.

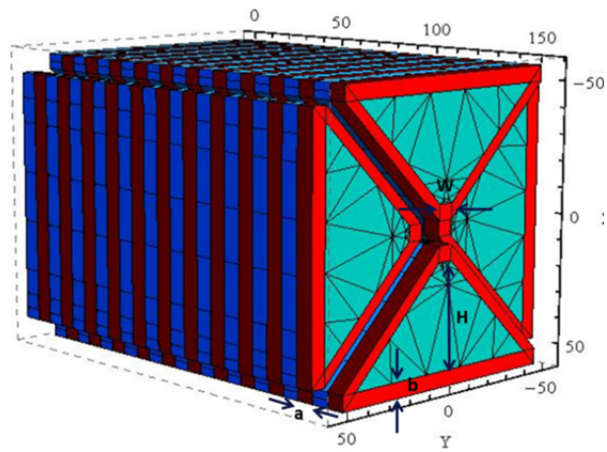

Figure 3: The Radia model for the helical SCU.

Different to the permanent magnet helical undulator APPLE-X whose gap and the longitudinal position of each array are adjustable the SCU helical undulator fixes the positions of all arrays. The pair of the horizontal arrays longitudinally is fixed longitudinally with respect to the pair of vertical arrays by a quarter of period. The polarization status is switched by changing the current in each coil. Therefore the Stokes parameters of such a SCU device are always zero to S$_2$: $S_2 = 0$. The other Stokes parameters S_0, S_1 and S_3 are able to be continuously changed. Both circular and linear polarization and ellipse polarization are achievable.

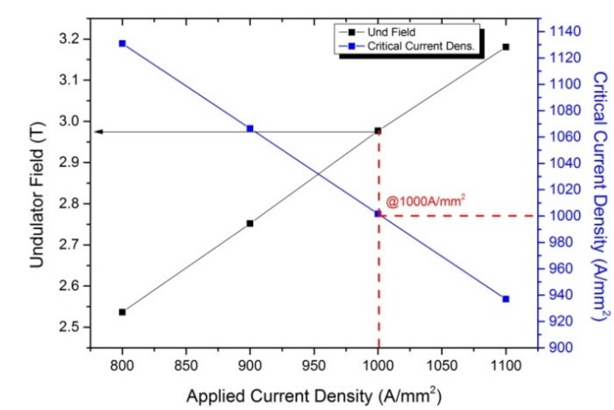

Figure 4: The helical undulator peak field and the critical current density with respect to the applied current density.

Several undulator periods have been simulated and the period 46mm is selected. Even in the linear mode it

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matches the maximum K in the soft X-ray beam line SASE3. Similar to the planar undulator we simulate the peak field and critical current density by taking use of Eq. (1) at different applied current densities. Figure 4 shows the results.

As the simulation results shown in Fig. 4 the applied current density equals to the critical current density at the value of 1000A/mm^2 and accordingly the maximum peak field is 2.98T. To be noticed, here the peak field is from one pair of magnet arrays and it is either vertical or horizontal field. It corresponds to the maximum linear K parameter. The maximum helical K value is therefore the factor of $\sqrt{2}$ larger. We summarize the parameters of the helical super conducting undulator U46 in Table 2.

Table 2: Parameters for the Helical U46

Parameter	Value	Unit
Period λ_u	46	mm
Coil cross section *a* &*b*	13 & 9	mm
Iron core size W&H	7 & 40	mm
Pole width	10	mm
Gap *g*	10	mm
Slit between arrays	2.12	mm
Max. current density	1000	A/mm^2
Max. peak field	2.98	T
Max. linear K, $K_{x,y}$	12.8	--
Max. circular K, $\sqrt{2}K_{x,y}$	18.1	--
Long. λ_r @17.5GeV (Linear)	1.6	nm

CONCLUSION

In this paper we simulated the fields of two types of super conduction undulators, one is the planar undulator with the period of 18mm and the other is the helical undulator with the period 46mm. Both undulators match the parameters for the European XFEL. The planar undulator U18 can generate high photon energy SASE up to 100 keV with available tunnel length. Since the superconducting undulator is high in the magnet field that the factor of 1.5 of the tunability to the photon energy is achievable. The helical U46 covers the same photon energy range with the existing soft x-ray beam line SASE3 even in the linear mode. It can generate both circular and linear polarization.

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