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Magnetic design of a 14 mm period prototype superconducting undulator

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ABSTRACT

In this paper we report the design of a 14 mm period prototype superconducting undulator that is under fabrication at Insertion Device Development Laboratory (IDDL) at Devi Ahilya Vishwavidyalaya, Indore, India. The field computations are made in RADIA and results are presented in an analytical form for computation of the on axis field and the field on the surface of the coil. On the basis of the findings, a best fit is presented for the model to calculate the field dependence on the gap and the current density. The fit is compared with Moser-Rossmanith formula proposed earlier to predict the magnetic flux density of a superconducting undulator. The field mapping is used to calculate the field integrals and its dependence on gap and current densities as well.

1. Introduction

In recent years there are interests and advantages of using super conducting undulator (SCU) for synchrotron radiation and free electron laser (FEL) applications over pure permanent magnet (PPM) or hybrid undulator (HU) due to a variety of reasons. Higher magnetic fields allow reducing the undulator lengths which are often required for table top FEL facility. Short period undulators are feasible, but not in the case with PPM or HU structure due to finite size of the magnets and reduced magnetic field strengths. The superconducting undulator is lesser sensitive to radiation damage thus allowing a longer life of operation at smaller gaps. The SCU leads to a simpler K – control through the current flowing in the coils as compared to the massive and difficultly adjustable gap in PPMs and HUs. A superconducting magnet [1–4] is built using coils wound with superconducting commercial wires. They are cooled down to cryogenic temperatures between 1.8 K and 6 K typically. At this temperature range, they can produce stronger magnetic fields than ordinary iron-core electromagnets due to the ability to carry larger current densities without electrical losses. In superconducting undulators, the magnetic field is created by a pair of identical electromagnets wound on ferromagnetic cores. The two poles are separated by a gap. Each electromagnet is a series of racetrack coils with alternating current pattern to create an undulatory magnetic field on axis. Several superconducting undulators were built around the globe and operated in liquid helium at 4.2 K [5–16]. Over the years, the interests and efforts have grown on using superconducting technology on developing advanced SC undulator schemes such as a transverse gradient superconducting undulator [17] and elliptically polarized undulator as well [18,19].

Wallen et al. [20,21] using RADIA model reported calculation of magnetic flux density and field integrals of an SCU suitable for installation at the ESRF storage ring. In this paper we follow the software package RADIA to model a 14 mm period proto-SCU at IDDL, DAVV, Indore, India. In Section 2, the magnetic design layout is detailed with the end field scheme. In Section 3, the field computations are made and results are presented in an analytical form for computation of on axis field and the field on the surface of the coil. An empirical fit is obtained and compared with Moser-Rossmanith formula for the magnetic flux density at different current densities in Section 3. The field mapping is used to calculate the field integrals versus gap and current densities as well.

2. Mechanical design & RADIA modeling

It is proposed to build a 10 periods, 14 mm long each period proto-SCU at DAVV for field integral measurement studies. The superconducting magnet will be composed of racetrack coils connected in series and wound on two ferromagnetic poles made of carbon steel. To produce the undulatory field on axis, from one coil to the next, the current direction is required to be inverted. It will be done by alternating the winding for each adjacent coil. Superconducting commercial NbTi wire with a cross section of 1 mmx0.5 mm including its insulation are used in the calculation.

The SCU will consist of 26 poles and 25 coils which are numbered from 1 to 51. Fig. 1 shows 3D view of the mechanical design, without coil packs of the superconducting undulator. The regular pole is 2 mm

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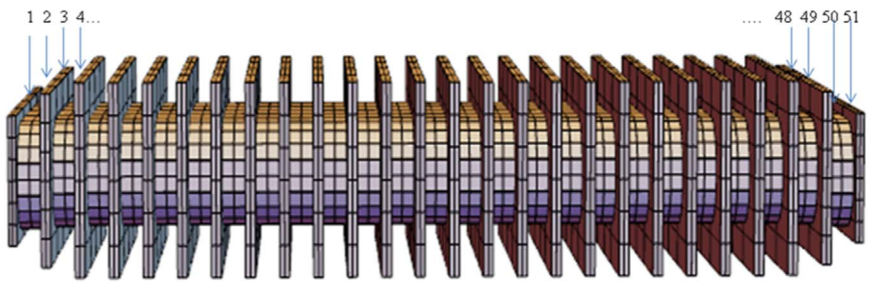

Fig. 1. SCU structure without coil packs.

in length (longitudinal direction), 40 mm in width (horizontal direction) and 8 mm in height (vertical direction). The regular coil length with five turns is 5 mm (5 turnsx1 mm) and the coil height with 16 layers is 8 mm (16 layersx0.5 mm). The coil width is same as the pole width. The undulator begins with a pole and runs with pole-coil–pole arrangement numbered from 1 to 51 and ends with a pole in an asymmetric field configuration. The poles-coils numbered from 5 to 47 are regular in size.

The end field configuration in our scheme is 1:3/4:1/4. The end poles–coils are numbered as 1-2-3-4 at the left end and numbered as 48-49-50-51 at the right end (Fig. 1). The end pole at 1 is 1.6 mm in length and pole 3 is 1.96 mm in length. The coils numbered as 3 and 4 are 5 mm in longitudinal length. The pole 1 and 3 is 2 mm (¼) and 6 mm (¾) in height respectively. The coil 2 will be 2 mm in height (0.5 mmx4) and coil No. 4 will be 6 mm in height (0.5 mmx12). The right end of the SCU has similar end-design. The total length of the magnetic structure (22 regular poles=44 mm, 21 coils=105 mm, end design=2×13.56 mm (2x(1.6 mm+5 mm+1.96 mm+5 mm))) reaches a total length of 176.12 mm. Fig. 2 presents a longitudinal view of the complete superconducting undulator assembly. The structure will be held by a magnet support stand in an adjustable gap ranging from 5 to 8 mm. The groove dimension is 5 mmx8 mm. The core grooves and the pole widths will be machined within a tolerance of 10 µm. The flatness of the grooves will be kept within 10 µm as well.

The dimensions of the poles and coils are used in RADIA to estimate the performance of the proto-SCU. The magnetic flux density at a gap of 3–11 mm is plotted in Fig. 3 for a current density of 800 A/mm^2. The analysis predicts a field of > 1 T at 5 mm gap. The integrals i.e.

$$I_1 = \int_0^z B_y(\xi)d\xi, \quad I_2 = \int_0^z I_1(\xi)d\xi \tag{1}$$

are called first and second field integrals, respectively and are the quantities of interests for design of a good quality undulator. These integrals are proportional to the angular and change of position of the electron beam at the undulator exit. The above equations when multiplied by -e/(γmc) gives the angular and trajectory offset. Setting $-e/mc$=565 T^{-1} m^{-1}and γ=1957E (GeV), we get,

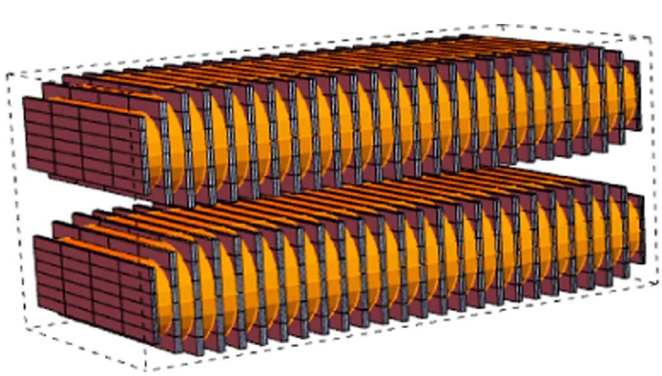

Fig. 2. SCU structure with coil packs.

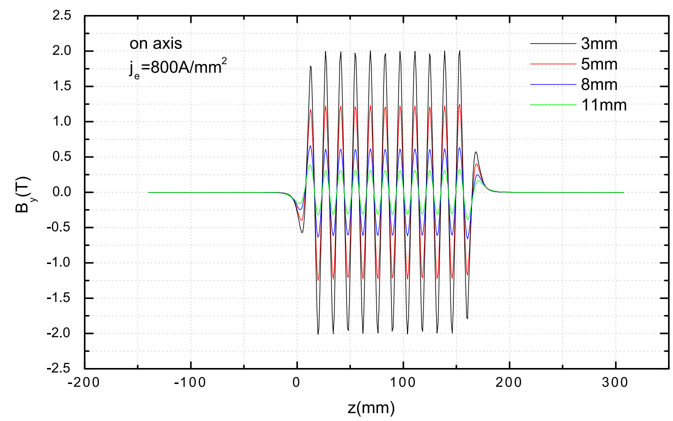

Fig. 3. Magnetic flux density versus longitudinal position.

$$\frac{-e}{\gamma mc} = \frac{0.298}{E}\,\mathrm{T^{-1}\,m^{-1}},\ with\ \ E\ \ is\ \ in\ \ \mathrm{GeV} \tag{2}$$

The first field integral and the second field integral versus gaps and current densities are evaluated and plotted in Figs. 4–7.

In Fig. 8 we calculate the magnetic flux density at 5 mm gap at different current densities. In Fig. 9, on-axis magnetic flux density versus gap is plotted for current densities from 700 to 1800 A/mm^2. In Fig. 10, the on-axis magnetic flux density versus current density is plotted for different gaps. In Figs. 11 and 12 the calculations are made at the surface of the coil.

3. Results & discussion

The design details of a proto-SCU structure have been discussed. The code RADIA has been used extensively for the computation of the

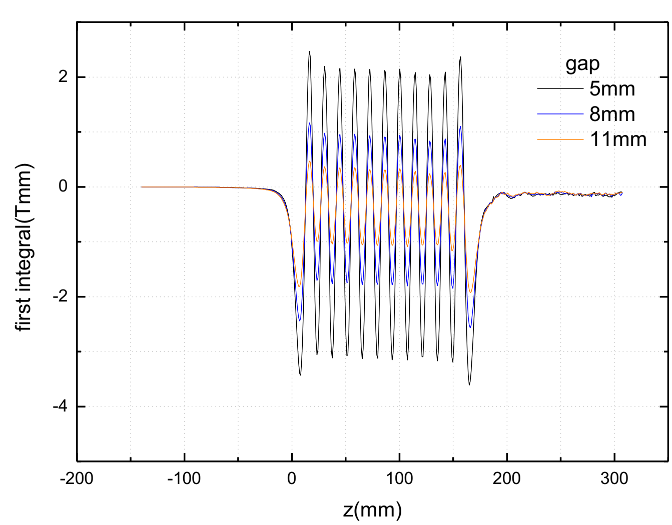

Fig. 4. First field integral for different gaps at current density of 800 A/mm^2.