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Field quality of 1.5 m long conduction cooled superconducting undulator coils with 20 mm period length

S Casalbuoni[1], N Glamann[1], A W Grau[1], T Holubek[1], D Saez de Jauregui[1], C Boffo[2], Th A Gerhard[2], M Turenne[2], W Walter[2]

[1]Institute for Beam Physics and Technology, Karlsruhe Institute of Technology, Hermann-von-Helmholtz-Platz 1, D-76344 Eggenstein-Leopoldshafen, Germany
[2]Babcock Noell GmbH, Würzburg 97080, Germany

E-mail: sara.casalbuoni@kit.edu

Abstract. The Institute for Beam Physics and Technology (IBPT) at the Karlsruhe Institute of Technology (KIT) and the industrial partner Babcock Noell GmbH (BNG) are collaborating since 2007 on the development of superconducting undulators both for ANKA and low emittance light sources. The first full length device with 15 mm period length has been successfully tested in the ANKA storage ring for one year. The next superconducting undulator has 20 mm period length (SCU20) and is also planned to be installed in the accelerator test facility and synchrotron light source ANKA. The SCU20 1.5 m long coils have been characterized in a conduction cooled horizontal test facility developed at KIT IBPT. Here we present the local magnetic field and field integral measurements, as well as their analysis including the expected photon spectrum.

1. Introduction

Superconducting undulators can produce, with respect to permanent magnet ones, a higher peak field on axis for the same vacuum gap and period length, allowing to increase the brilliance and the tunability of the photon spectrum. The collaboration between the Institute for Beam Physics and Technology (IBPT) at the Karlsruhe Institute of Technology (KIT) and the industrial partner Babcock Noell GmbH (BNG) is developing superconducting undulators for ANKA and low emittance light sources. The first full length device with 15 mm period length has been successfully tested in the ANKA storage ring for one year [1]. Presently the collaboration is focused on the development of a full scale superconducting undulator with 20 mm period length with 75.5 full periods (SCU20). The device is conduction cooled and wound with a round NbTi wire with a diameter of 0.7 mm; each full winding package consists of 113 single turns and the magnetic gap is 8 mm. More details on the layout are provided in References [2,3].

The coils have been measured in a unique test facility developed allowing precise measurements in vacuum and at low temperatures of the field profile and field integrals of superconducting undulator coils. The coils are tested in the KIT IBPT test facility CASPER II [3] in a horizontal arrangement and conduction cooled, in a similar configuration to the one that they will have in the final cryostat. The results of the training, the stability and the thermal behavior of the coils are described in Reference [4]. The field integrals are measured using a stretched wire, while the local field profile along the coils is measured using a Hall probe mounted on a sledge which moves along the coils and is kept below 50 K.

2. Field integrals

With the aim of minimizing the horizontal first and second field integrals the end field design shown in Figure 1 has been chosen. Two auxiliary coil pairs and Helmholtz coils are wound with a NbTi round wire with 0.25 mm diameter. The first groove of the main coil has 23 turns and the second one 53 turns. Similar configurations are at all 3 other ends.

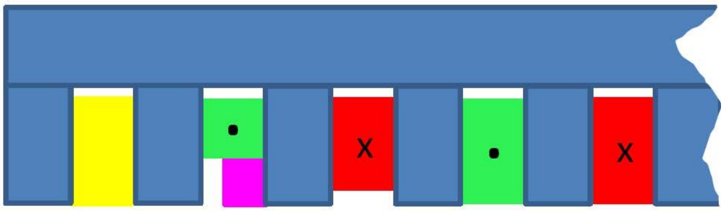

Figure 1. End field configuration at the beginning of the upper coil. In yellow are indicated auxiliary coils 1 (AUX1), in magenta auxiliary coils 2 (AUX2), and in red and green the main coil, wound in opposite direction to create the alternating magnetic field. Similar configurations are at all 3 other ends.

To keep the first and second vertical field integrals (I_{1v} and I_{2v}) within the specified values, only auxiliary coils 1 (AUX1) and the Helmholtz coil downstream (HH DS) are needed. The AUX1 upstream and downstream are connected to the same power supply and are used to compensate the second vertical field integral, while the HH DS is used to compensate the first vertical field integral. All other correction coils are not needed. The measured values of the first and second vertical and horizontal field integrals, presented in Table 1 for five different currents in the main coil in the range from 50 to 395 A, are all within the specified values: $|I_{1v}| < 3\ 10^{-5}$ T m, and $|I_{2v}| < 4\ 10^{-4}$ T m^2.

The horizontal field integrals are specified: $|I_{1h}| < 3\ 10^{-6}$ T m, and $|I_{2h}| < 10^{-5}$ T m^2. In order to reach these values correctors will be added outside the cryostat.

Table 1. First and second vertical field integrals minimized by powering the AUX1 and HH DS coils to values up to 5.6 A and 0.82 A, respectively.

Current (A)	I_{1v} (10^{-5} T m)	I_{2v} (10^{-4} T m^2)
50	0.6	-0.29
100	0.5	0.64
200	0.6	0.09
300	0.9	0.28
395	1.3	-0.8

3. Integral field multipoles

The first vertical field integral has been measured at different positions of the transverse coordinate x at the five different currents in the main coils indicated in Table I, and powering the AUX1 and HH DS coils to the same currents minimizing the first and second vertical field integrals on the magnetic axis (x = y = 0 mm, being y the coordinate along the magnetic gap).

The vertical integrated field multipoles have been calculated from the measurements of I_{1v} shown in Figure 2.

Only the vertical integrated field multipoles have been measured. The quadrupole Q, sextupole S and octupole component O are for all measured currents: |Q|<0.005 T, |S|<5 T/m and |O|<15 T/m^2. With these values of the integrated field multipoles the dynamic aperture for the 2.5 GeV optics is not affected.

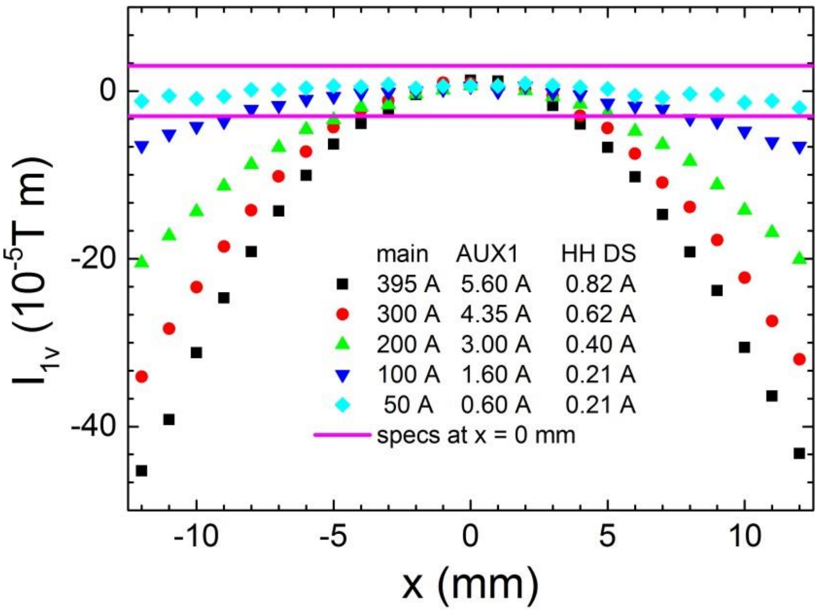

Figure 2. Measurements of the vertical first field integral as a function of the transverse coordinate x at different currents in the main coils. These measurements are usedto calculate the multipole integral components.

4. Longitudinal field profile

With an operating current of 395 A and a magnetic gap of 8 mm an average peak field of 1.187 T is reached. The measured absolute values on axis (x = 0 mm) of the peaks of the magnetic field profile are plotted and compared to the simulated one with Radia [5] with a current in the main coils of 395 A and in the AUX1 coils of 5.6 A, see in Figure 3 (lower plot). The simulation is performed considering the deviations measured at room temperature of the half period length before winding < 20 µm and of the pole height < 50 µm and winding height < 100 µm measured after impregnation. Figure 3 (upper plot) shows also the half period length obtained from the measured and simulated field profiles. The larger deviation of the period length observed at room temperature is at the connection of the building blocks of the coils. The smaller average period length observed in cold conditions is due to the thermal contraction of the yoke. The larger deviations observed in the half period length in cold conditions with respect to the ones at room temperature might be due to the loosening of the connections between the blocks as well as to an increase of the winding height deviations. This could explain a larger variation also in absolute value of the peak field on axis of the measured peaks with respect to the ones simulated.

The roll off has been obtained at each pole by measuring the longitudinal field profile with the same Hall probe positioned at x = 0 mm, -10 mm, +10 mm. In Figure 4 are reported the absolute values of the maxima and minima measured with 200 A in the main coils, 3 A in the AUX1, and 0.4 A in the HH DS coils.

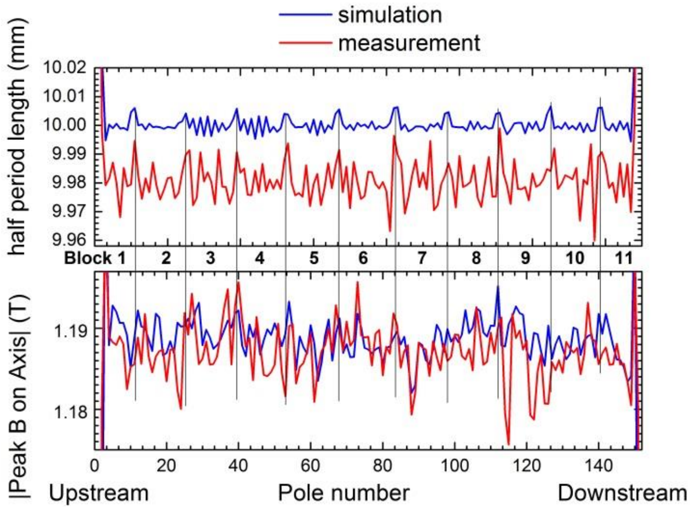

Figure 3. Comparison of the half period length and of the peak field on axis as a function of the pole number (counting from upstream to downstream) of the measured and simulated magnetic field. The dashed line shows the peak field of the field profile simulated with Radia considering the mechanical accuracies (pole height, half period length and winding height deviations from the ideal values) measured at room temperature.

The calculated roll off is defined as follows:

$$\text{Roll off} = \frac{|B(x = \pm 10\ \text{mm}) - B(x = 0\ \text{mm})|}{|B\ (x = 0\ \text{mm})|}.$$

The roll off obtained from the local magnetic field measurements at different currents in the main coils and in the correction coils to minimize the vertical field integrals is below 0.5% at higher currents and it increases up to 0.7-0.8 % at lower currents. The roll off measured for the five currents in the main coils as indicated in Table I induces a negligible dynamic kick [6], and does not constitute a problem for the operation of the SCU20.

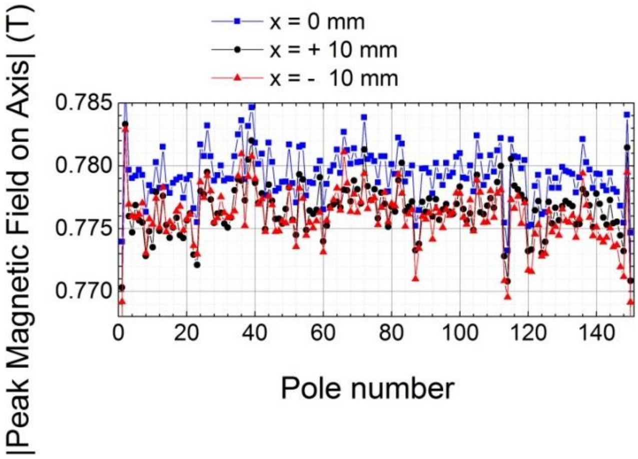

Figure 4. Peak magnetic field measured along the SCU20 coils powered with a current of 200 A at x = 0 mm, +10 mm and –10 mm.

5. Calculated spectrum

The advantage of using the SCU20 with respect to an ideal (without mechanical errors and perfect end fields) cryogenic permanent magnet undulator (CPMU) with the same parameters as the one built at SOLEIL [8] for the same vacuum gap of 7 mm can be appreciated in Figure 5. The CMPU has a period length of 18 mm (CPMU18), a peak field of 0.82 T (highest field reachable with PrFeB) and 2 m magnetic length.

The flux calculated with B2E [7] from the measured field at maximum current of the SCU20 is compared in Figure 5 with the flux of a CPMU18 with an ideal field, that is without mechanical errors and perfect end fields.

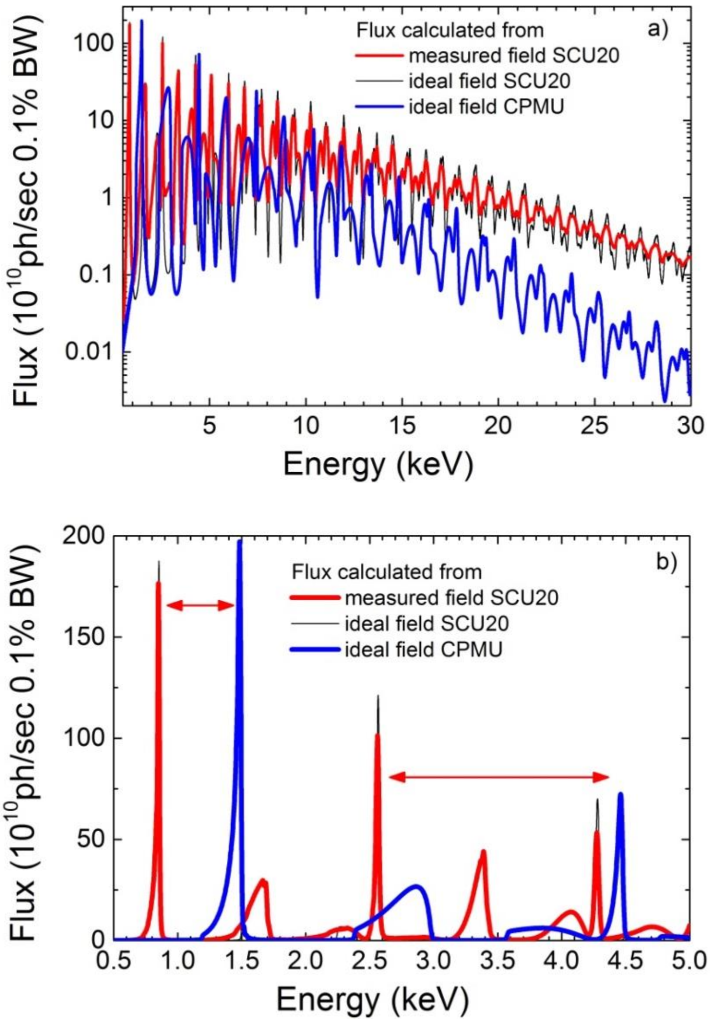

Figure 5. a) Flux through a slit of 50 µm x 50 µm placed at 10 m from the source calculated with B2E for the measured magnetic field of the SCU20 at 395 A (red line), as well as for a SCU20 (black line) and a CPMU18 (blue line) with ideal field profile (without mechanical errors and perfect end fields), respectively with 1.5 m and 2 m magnetic length. b) Zoom of a) in the low energy range and with a linear scale: the red arrows indicate the extended energy region available with the SCU20 with respect to the CPMU18.

Please note that the magnetic length considered is 1.5 m for SCU20 and 2 m for the CPMU18.

To give a flavor of a comparison in terms of brilliance, the flux is calculated through a pinhole of 50 µm x 50 µm at 10 m from the source. The spectra presented have been simulated using the ANKA beam parameters: beam energy 2.478 GeV, beam current 100 mA, energy spread 0.001, horizontal emittance 41 nm rad, vertical emittance 0.3 nm rad, horizontal beta function 19 m, and vertical beta function 1.7 m.

6. Discussion

The flux calculated from the measured field of the SCU20 is compared also to the flux of SCU20 with an ideal field. As expected, a slight reduction (less than 28% up to 30 keV) in flux for the odd harmonics, due to the mechanical errors and to the non-ideal end field configuration, is observed.
The comparison with the ideal CPMU18 with the same parameters as the one in use at SOLEIL shows the larger flux/brilliance of the SCU20 at high energies up to factor of five (see Figure 5a) and at low photon energies the energy regions allowed with the SCU20, and not reachable with the CPMU18 (see Figure 5b).

7. Conclusion

The field integrals, the longitudinal magnetic field profile and the roll off of the 1.5 m long coils of the SCU20 have been measured in the test facility CASPER II.

The magnetic field profile has been used to simulate the expected photon spectrum at ANKA. The advantages of the spectrum produced by the measured field profile of the SCU20 with respect to an ideal PrFeB CPMU18 (without mechanical errors and perfect end fields) with the same parameters as the one built at SOLEIL and same beam stay clear have been demonstrated (see Figure 5).

References

[1] Casalbuoni S, Cecilia A, Gerstl S, Glamann N, Grau A W, Holubek T, Meuter C, Saez De Jauregui D, Voutta R, Boffo C, Gerhard Th, Turenne M and Walter W 2016 Characterization and long term operation of a novel superconducting undulator with 15 mm period length in a synchrotron light source *Phys. Rev. Accel. Beams* **19** 110702

[2] Casalbuoni S, Gerstl S, Glamann N, Grau A, Holubek T, Saez De Jauregui D, Boffo C, Turenne M and Walter W 2014 Test of short mockups for optimization of superconducting undulator coils *IEEE Trans. Appl. Supercond.* **24-3** 4101905

[3] Grau A, Casalbuoni S, Gerstl S, Glamann N, Holubek T, Saez De Jauregui D, Voutta R, Boffo C, Gerhard Th, Turenne M and Walter W 2016 Characterization of 30-cm-Long Superconducting Undulator Coils With the Magnetic Measurement System CASPER II *IEEE Trans. Appl. Supercond.* **24-4** 4100804

[4] Grau A, Casalbuoni S, Glamann N, Holubek T, Saez De Jauregui D, Boffo C, Gerhard Th, Turenne M and Walter W 2017 Training and Characterization of 1.5m Long Conduction Cooled Superconducting Undulator Coils with 20 mm Period Length *Proceedings of the 8th Int. Particle Accelerator Conf. (IPAC'17)* Copenhagen, Denmark TUPAB036

[5] Chubar O, Elleaume P, Chavanne 1998 A 3D Magnetostatics Computer Code for Insertion devices *J. Synchrotron Rad.* **5** 481-484

[6] Safranek J, Limborg C, Terebilo A, Blomqvist K I, Ellaume P, Nosochkov Y 2002 Nonlinear dynamics in a SPEAR wiggler *Phys. Rev. ST Accel. Beams* **5** 010701

[7] Elleaume P, Marechal X 1991 B2E. A software to compute Synchrotron Radiation from Magnetic field data Report ESRF-R/ID-9154

[8] Benabderrahmane C, Valleau M, Ghaith A, Berteaud P, Chapuis L, Marteau F, Briquez F, Marcouille O, Marlats J L, Tavakoli K, Mary A, Zerbib D, Lestrade A, Louvet M, Brunelle P, Medjoubi K, Nagaoka R, Herbeaux C, Bechu N, Rommeluere P, Somogyi A, Chubar O, Kitegi C, Couprie M E 2017 Development and operation of a $Pr_2Fe_{14}B$ based

cryogenic permanent magnet undulator for a high spatial resolution x-ray beam line *Phys. Rev. Accel. Beams* **20** 033201