CALCULATED SPECTRA FROM MAGNETIC FIELD MEASUREMENTS OF 1.5 M SUPERCONDUCTING UNDULATOR COILS

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Abstract

In this contribution we report on the spectra calculated from the field measurements performed in a liquid helium bath of 1.5 m superconducting undulator coils. The coils are foreseen for a superconducting undulator demonstrator with a period length of 15 mm planned to be tested in ANKA (ANgstrom source KArlsruhe). The spectral performance of the measured field and of a field with a r.m.s. phase error of about $6°$, obtainable by keeping at 4 K the measured mechanical accuracies measured at room temperature, at ANKA and at low emittance sources is compared with the competing cryogenic permanent magnet technology.

INTRODUCTION

A new SCU demonstrator to be tested at ANKA (ANgstrom source KArlsruhe) is under development in collaboration with Babcock Noell GmbH (BNG) [1]. In this contribution we describe the spectral performance of the measured field of 1.5 m long undulator coils of the SCU demonstrator and of a field with a r.m.s. phase error of about $6°$, obtainable by keeping at 4 K the measured mechanical accuracies measured at room temperature of the SCU demonstrator, at ANKA and at low emittance sources. The results are also compared with the competing cryogenic permanent magnet technology.

Superconducting undulators (SCUs) have the potential to produce, for the same period length and the same vacuum gap, higher fields with respect to permanent magnet devices. A detailed comparison is made in Ref. [2]. In order to maximize the spectral properties, permanent magnet devices installed in third generation storage rings are required to achieve extremely small r.m.s. phase errors of about $1° − 3°$. Because of the lack of a shimming technique for SCUs easily applicable to long devices (> 1 m) it is of course important to evaluate the real requirements on the r.m.s. phase errors for present and future applications: some considerations are reported.

FIELD MEASUREMENTS

Local field measurements of the 1.5 m long coils have been performed in a liquid helium bath cryostat at CERN at several currents between 20 A and 145 A at 4.4 K and

with 165 A at 2 K, moving the Hall probes along the undulator axis in the middle of the magnetic gap in steps of 50 μm [3]. The coils were held in a stainless steel support structure, which fixed the gap at room temperature to 8.00 ± 0.01 mm. Due to the thermal contraction of the stainless steel support structure, the gap is reduced at low temperatures from 8 mm to 7.75 mm. The measured field at 135 A with a gap of 7.75 mm in the middle of the undulator coils is shown in Fig. 1, as the magenta line. The bending of the field, believed to be due to the differential thermal contraction between the stainless steel support structure and the cobalt-iron yoke, could be partially compensated by applying mechanical shims along the support structure that increase the gap to 8.25 mm. This is demonstrated in Fig. 1, see blue line. This procedure can be used to shim fixed-gap undulators. The measured field shows, after mechanical shimming, a r.m.s. phase error of $7.4°$ on 106 poles, over a length of 0.795 m [3]. In order to keep the mechanical tol-
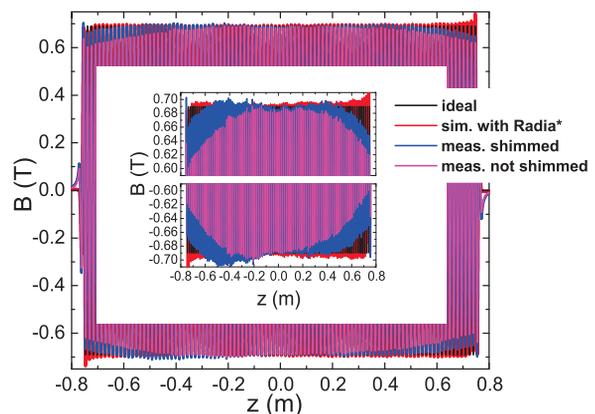
Figure 1: Profiles of the measured field before (magenta line) and after (blue line) mechanical shimming, of the ideal field (black line) and of the field simulated with Radia [4] (red line) using the pole height ($\lesssim 50$ μm) and the half period length ($\lesssim 10$ μm) deviations measured for the two coils at room temperature [1]. The inset shows a zoom of the positive and negative field peaks.

erances of the two 1.5 m long coils, several measurements have been performed during the manufacturing procedure. The pole height deviations were always measured within 50 μm (±25 μm), while the deviation from the plates thickness ($\lambda_U/2$) always within 10 μm (±5 μm) [1]. The field calculated from the Radia [4] simulations using the pole

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height and the half period length deviations measured for the two coils at room temperature is shown in Fig. 1 (red line). It has an r.m.s phase error of $5.6°$ over 186 poles. The use of mechanical shims to reduce the bimetallic effect, applicable to fixed gap undulators, together with further adjustment to keep the gap uniform to within 40 μm, would make it possible to reach a r.m.s phase error of $\sim 3.5°$ without additional correction coils. For the installation of the SCU demonstrator at ANKA, where the gap is movable, BNG will prebend the coils at room temperature to try to compensate the bending measured at 4 K.

FLUX CALCULATIONS

The photon flux calculated with B2E [5] using the four field profiles and the parameters indicated in Table 1 for ANKA, the Diamond Light Source (DLS) and MAXIV is reported as a function of photon energy in Fig. 2. Compared are also the convolutions of the flux produced by an ideal SCU with λ_U=15 mm, by the measured shimmed field and by an ideal cryogenic permanent magnet undulator (CPMU) with λ_U=17.7 mm (cyan line) [6]. The

Table 1: Parameters used to calculate the flux at 10 m from the middle of the undulator through a slit with the dimensions (horizontal x vertical) as indicated below for ANKA [7], DLS [8] and MAXIV [9].

	ANKA	DLS	MAXIV
E [GeV]	2.5	3	3
I [A]	0.2	0.3	0.5
$\Delta E/E$	0.001	0.001	0.001
ϵ_x [nm rad]	41	2.63	0.27
ϵ_y [nm rad]	0.3	0.027	0.008
β_x [m]	14.7	4.8	9
β_y [m]	1.93	1.43	4.8
v. gap [mm]	7	5	4
m. gap [mm]	8	6	5
B_{SCU} [T]	.69	1.1	1.4
B_{CPMU} [T]	0.707	1.04	1.263
slit [mm^2]	4x0.9	1.2x0.6	0.68x0.64

main plot shows a comparison of the flux from 1 to 10 keV, while the two insets show the comparison at higher photon energies. The maximum field value corresponds to the measured field value of the two 1.5 m long coils with the magnetic gap and vacuum gap shown in Table 1. The minimum magnetic (vacuum) gap allowed now at ANKA is 8 mm (7 mm). An upgrade of ANKA with a full energy injector should allow a 6 mm magnetic gap (5 mm vacuum gap) and consequently B=1.1 T. For ANKA the slit dimensions have been chosen to collect $\pm2\sigma$ of the first harmonic produced by a peak field on axis B=1.1 T. Already with the measured shimmed field, the flux of the SCU is in some energy regions higher than the one from the CPMU. The flux produced by the field simulated with Radia taking into account the mechanical tolerances measured at room tem-
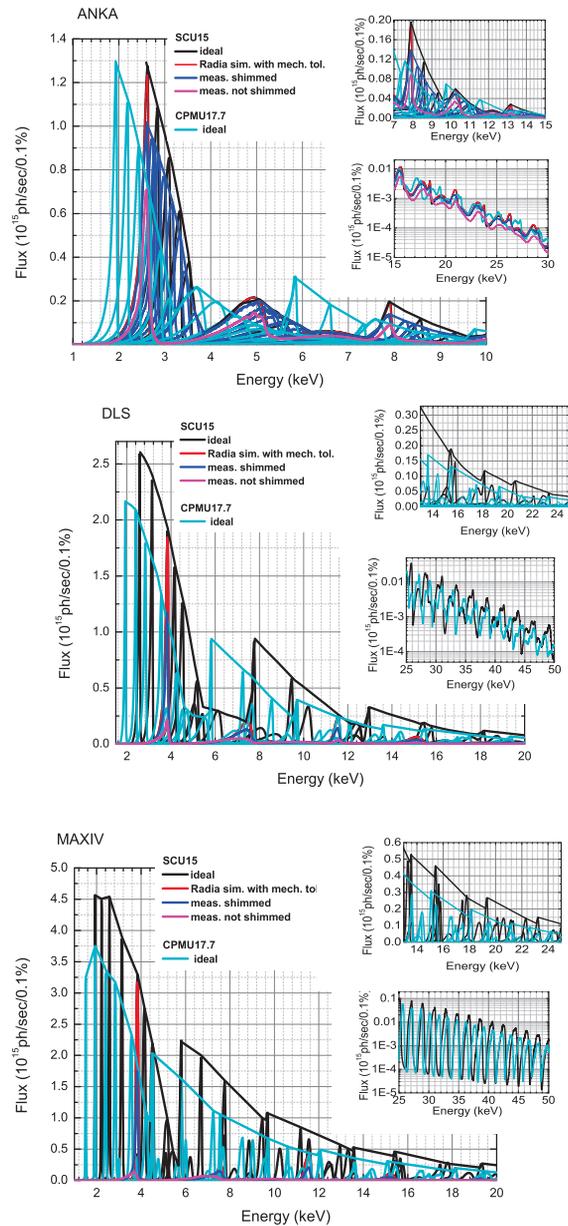
Figure 2: Flux calculated with B2E [5] using the four fields shown in Fig. 1 using the parameters shown in Table 1 at ANKA (up), DLS (middle) and MAXIV (bottom). Compared are also the convolutions of the flux produced by an ideal SCU with λ_U=15 mm, by the measured shimmed field and by an ideal CPMU with λ_U=17.7 mm [6]. The two insets show the comparison at photon energies > 10 keV.

perature and with a r.m.s phase error of $5.6°$ is reduced not more than 10% at the harmonics with respect to the one produced by the ideal field. This is demonstrated up to the 15th harmonic in the upper plot of Fig. 3. The same holds for the flux produced at the DLS and at MAXIV calculated with the parameters reported in Table 1. No significant flux reduction is seen in the higher harmonics even

in case of MAXIV, which has an emittance two orders of magnitude smaller than ANKA. The reason is that for this aperture and for r.m.s phase errors $\sim 6°$, the flux reduction at the higher harmonics is dominated by the energy spread of 0.001, which is the same for all the three machines. In Fig. 2 the plots obtained for DLS and MAXIV of the flux through a slit collecting $\pm 2\sigma$ of the first harmonic produced by the maximum allowed peak field on axis (see Table 1) show that the ideal SCU and a SCU with $\sim 6°$ produce a higher flux than the CPMU almost in all energy regions.
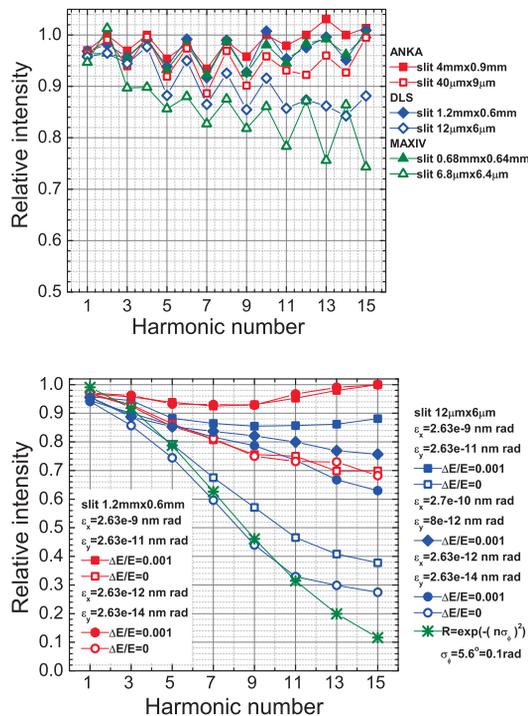
Figure 3: Ratio of the flux produced by the field simulated with Radia taking into account the mechanical tolerances measured at room temperature and with a r.m.s phase error of $5.6°$ to the one from an ideal field at the different harmonics. Upper plot: for all three synchrotron radiation sources with the parameters reported in Table 1. Lower plot: for the DLS parameters reported in Table 1 varying the emittance, the energy spread and the aperture.

Because of the lack of a shimming technique for SCUs easily applicable to long devices (> 1 m) it is of course important to evaluate the real requirements on the r.m.s. phase errors for present and future applications. The requirements depend on the chosen figure of merit, i.e. the peak angular flux density or the flux through a finite angular acceptance. In this last case the requirements depend on the angular acceptance and are more stringent for smaller angular acceptances. The ratio R of the on axis peak angular flux density to the ideal one is for zero emittance and zero energy spread for the nth harmonic $R_n = \exp(-(n\sigma_\phi)^2)$ [10], where n is the harmonic number. In this case, for a r.m.s. phase error of $6°$, the on axis peak angular flux density is strongly suppressed (re-

duction $\gtrsim 70\%$) after the 11th harmonic. The effect of a r.m.s. phase error of $6°$ on the flux through a finite angular acceptance for different apertures depending on the beam emittance and on the beam energy spread has been studied. From the results reported in the lower plot of Fig. 3 it can be concluded that even considerably reducing the aperture (factor of 100 to what used for DLS in Table 1) a r.m.s. phase error of $\sim 6°$ reduces the flux at the higher harmonics more than 30% only when reducing the energy spread to zero or reducing the emittance to values two orders of magnitudes smaller than what planned for machines like MAXIV and NSLSII. We can then summarize that a r.m.s. phase error of $\sim 6°$ is good enough (flux reduction $< 25\%$) for the existing and planned storage rings up to the 15th harmonic.

CONCLUSIONS

The SCU demonstrator coils with $7.4°$ r.m.s. phase error over half of the undulator length overperform in terms of flux the one of an ideal CPMU as built for DLS [6]. Considering the spectral performance of a field with a r.m.s. phase error of about $6°$, obtainable by keeping at 4 K the measured mechanical accuracies measured at room temperature of the SCU demonstrator, we can conclude that a r.m.s. phase error of $\sim 6°$ is good enough (flux reduction $< 25\%$) for the existing and planned storage rings up to the 15th harmonic.

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