# SPECTRAL CHARACTERISATION OF THE ANKA-SCU RADIATION

Axel Bernhard*, Florian Burkart, Sandra Ehlers, Golo Fuchert, Peter Peiffer,
Michael Wolf, Daniel Wollmann, and Tilo Baumbach, University of Karlsruhe
Barbara Kostka, Robert Rossmanith, Forschungszentrum Karlsruhe

*Abstract*

The ANKA superconductive undulator (SCU14) is continously operated since 2005. The main objetive of this operation was to investigate the interactions between the undulator and the stored electron beam and to characterise the undulator radiation. The latter was done with a short test beamline designed for spacially and spectrally resolved measurements of the undulator radiation intensity. This contribution summarises the results of these measurements. The spectra are cross-correlated with the magnetic field measurements carried out earlier.

## INTRODUCTION

Superconductive undulators generate higher magnetic fields for a given period length and gap width than state of the art permanent magnet undulators. They therefore promise to give medium scale synchrotron radiation facilities access to highly brilliant undulator radiation in the hard X-ray regime.

The superconductive undulator SCU14 at ANKA is the first and up to now only device of this kind being continously operated in a storage ring. Since its installation in 2005 several series of experiments on the interaction between the undulator and the electron beam[1, 2] and on the characterisation of the undulator radiation have been performed. For the latter a short test beamline was installed. In its final stage of expansion (operated in 2008) this beamline facilitated spacially and spectrally highly resolved radiation intensity measurements.

The spectral characteristics of undulator radiation are determined, both by the electron beam emittance and the quality of the magnetic field. The magnetic field of the SCU14 coils was mapped by Hall probe scans in a liquid Helium bath cryostat setup prior to their installation in the final SCU14-cryostat [3]. The accurate mapping of superconductive undulator fields in a cryogenic environment is very challenging. The complementary characterisation of the undulator radiation can serve as a proof for the reliability of the magnetic field data, limited, however, to the level of the electron beam quality and the numerical accuracy of the calculated radiation spectra.

Table 1: Design Parameters of the ANKA Superconductive Undulator SCU14

| | |
|---|---|
| period length | 14 mm |
| number of full periods | 101 |
| gap width | 8, 12, 16 mm |
| maximum field at 8 mm gap | 0.8 T |

## EXPERIMENTAL SETUP AND DATA PROCESSING

The design parameters of the SCU14 are summarised in Table 1. For test purposes the undulator can be operated with three fixed gap widths. The spectra presented below were measured at 16 mm and 8 mm and a current density of $J_{\mathrm{main}} = 400\,\mathrm{A/mm^2}$ and $J_{\mathrm{main}} = 500\,\mathrm{A/mm^2}$, respectively.

The measurements at 16 mm gap were performed with the current ANKA standard electron beam optics. For the 8 mm-gap operation an electron optics with a low vertical beta function in the straight sections was used [1, 4]. The Twiss parameters in the center of the straights for both optics are summarised in Table 2.

The undulator radiation was spectrally analysed with a channel-cut single crystal monochromator (Si, (111), covering a spectral range from 2.3 to 20 keV, $\Delta E/E \sim 10^{-4}$, built at the University of Wuppertal) and recorded with two ionisation chambers. The monochromator was calibrated at the Ti and Cr $K_\alpha$ absorption edges. Upstream of the monochromator a profile monitor was placed, equipped with a 50 $\mu$m-pinhole scannable in both transversal directions with a spacial resolution better than 50 $\mu$m. The distance between the centre of the undulator and the profile monitor was 14 m. To derive the spectral photon flux the

Table 2: Beam Parameters at the Center of the Undulator for the Two Electron Optics Used

| | Standard (16 mm gap) | vert. low beta (8 mm gap) |
|---|---|---|
| electron energy [GeV] | 2.483 | 2.483 |
| geom. emittance $\epsilon_x$ [nm rad] | 53.9 | 59.5 |
| coupling [%] | 0.1 | 0.2 |
| $\beta_x$ [m] | 13.4 | 14.7 |
| $\beta_y$ [m] | 8.7 | 1.9 |
| $\eta_x$ [m] | 0.4 | 0.4 |
| Energy spread [%] | 0.1 | 0.1 |

* axel.bernhard@physik.uni-karlsruhe.de

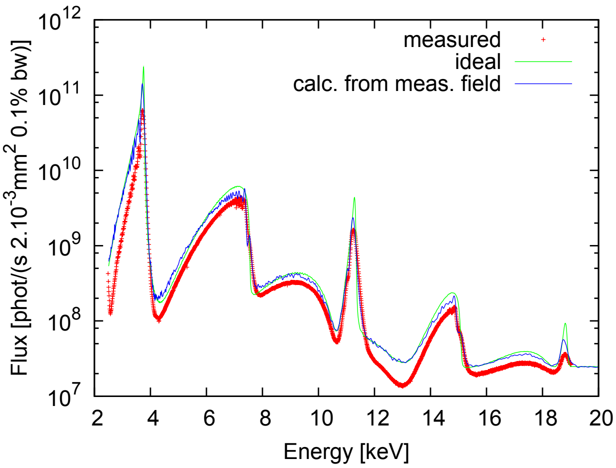


Figure 1: On-axis spectral photon flux through the 50 $\mu$m pinhole at 14 m distance from the source for 8 mm gap and $J_{\rm main} = 500\,{\rm A/mm^2}$: measured, calculated from an ideal and from the measured SCU14 field map.

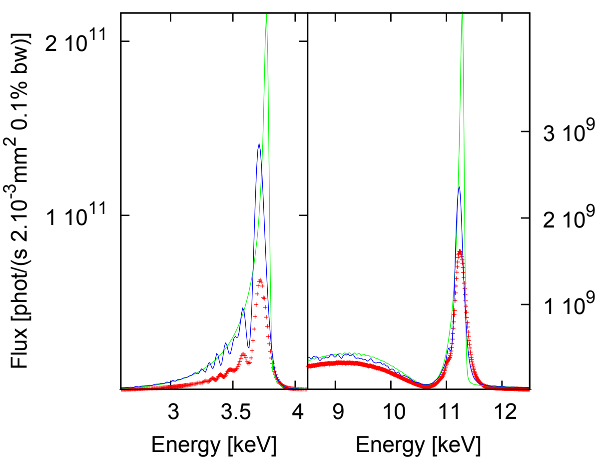


Figure 2: Details of the spectra shown in Fig. 1: fundamental and third harmonic in linear scale.

signals of the ionisation chambers were converted to the number of counted photons and subsequently absorption- and bandwidth-corrected.

In the following the measured angular and spectral photon flux distributions are compared to spectra calculated from the measured SCU14 field maps as well as from simulated field maps reflecting particular characteristics of the measured field. All calculations of radiation spectra shown below were performed with SPECTRA [5].

## RESULTS

Figures 1 and 2 show the on-axis spectrum of the SCU14 radiation at 8 mm gap and 500 A/mm$^2$, corresponding to a $K$-value of 0.47. The measured spectrum is compared to calculations from a simulated ideal undulator field and the measured SCU14 field maps, respectively. The measured spectrum agrees well with the expectations from the field measurements. In particular, the energy of the emission lines is precisely predicted, indicating that the measured field amplitude and therefore the absolute calibration of the Hall probes is reliable. It has to be noted, however, that calculated and measured photon flux differ by up to a factor of two in some regions. A careful analysis of the uncertainties in the measurement and data processing as well as in the simulation of the spectra revealed that the most probable source of this discrepancy is a reduction of the effective pinhole aperture in the order of 10% in diameter. The origin of this error will be further investigated.

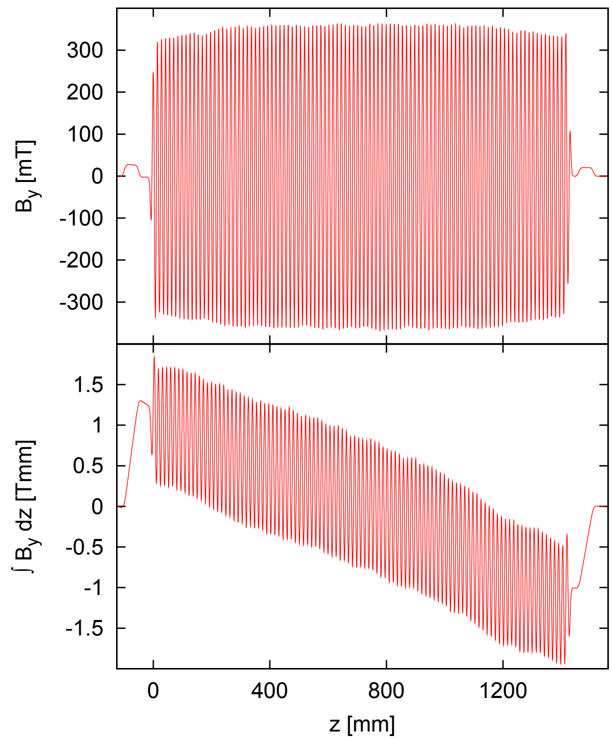


Figure 3: Measured field and first field integral map of the SCU14 for 8 mm gap and $J_{\rm main} = 500\,{\rm A/mm^2}$.

A comparison of the measured spectra to the simulation assuming an ideal undulator field shows that the spectral quality of the SCU14 radiation is largely dominated by the electron beam emittance. Nevertheless the measured spectra exhibit details which can be attributed to the field errors of the SCU14: Comparing the simulation shown in Fig. 2 for the measured to that for the ideal undulator field, the intensity is decreased, the intensity edge at the harmonic's energy is blurred and on the low energy side of each harmonic the intensity oscillates as a function of energy.

To correlate these spectral properties with the systematic field errors present in the SCU14, the influence of particular field errors on the angular spectral photon flux distribution was examined in detail for 16 mm gap and $J_{\rm main} = 400\,{\rm A/mm^2}$.

Figure 3 shows the measured field map of the SCU14

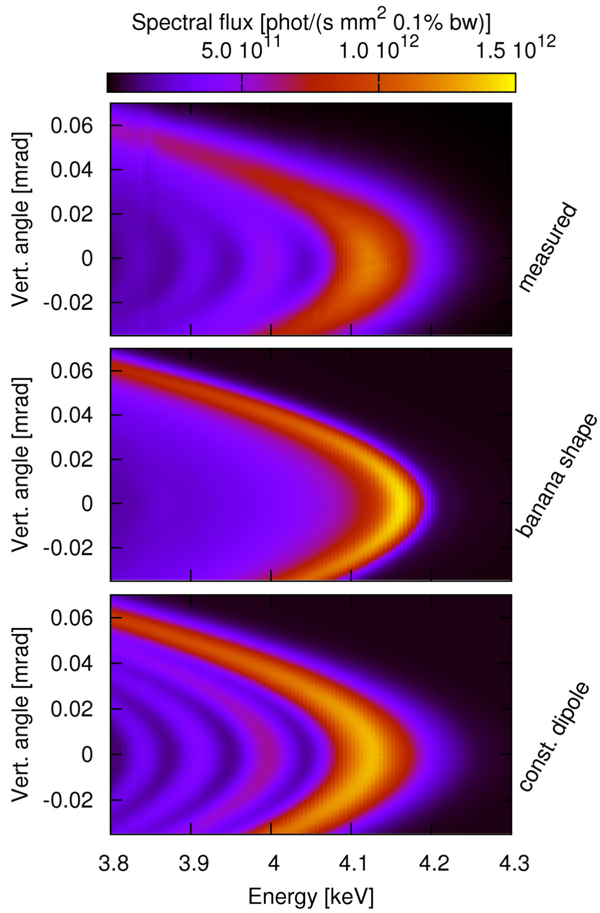


Figure 4: Vertical angular spectral distribution of the photon flux for 16 mm gap and $J_{\mathrm{main}} = 400\,\mathrm{A/mm^2}$: measured (top) and calculated from simulated field maps reflecting the systematic field amplitude decreas ("banana shape"-error, middle) and the constant dipole field error (bottom).

coils at $J_{\mathrm{main}} = 400\,\mathrm{A/mm^2}$ (measured at 8 mm gap) and the first field integral as a function of longitudinal position calculated by Riemann-summation of the field map. Three systematic field errors can be identified. First, the plot of the first field integral reveals a dipole field of $\sim 1.7\,\mathrm{mT}$ equally distributed over the full length of the undulator. Secondly, the field amplitude parabolically decreases by $\sim 10\%$ from the center to both ends of the undulator, caused by a banana-like distortion of both coils. Thirdly, a periodic variation of the field amplitude over 12.5 undulator periods in the order of $1\%$ is observed.

Angular spectral photon flux distributions were simulated using artificial field maps, reflecting each particular of these systematic field errors and combinations of them. Fig. 4 shows two of these simulations and the measured distribution.

The simulations show that the intensity oscillations can clearly be attributed to the constant dipole error. Their period and amplitude sensitively depend on the dipole field strength. In the example discussed here the estimated dipole field is $\sim 1.2\,\mathrm{mT}$. The intensity oscillations can be interpreted as a finite length effect in the spectral function of the undulator [6]. Due to the curvature of the trajectory the number of periods contributing to the coherent emission in forward direction and therefore the correlation length decreases. Subsequently, in frequency space, both amplitude and period of the interference maxima of second and higher order increase. In principle this finite length effect is always present but more or less concealed by field errors, electron beam divergence and angular integration over the beamline aperture.

The constant dipole field turns out to have by far the largest influence on the spectral characteristics of the SCU14 undulator radiation. The effect 10% systematic field amplitude decrease effect on the radiation spectrum is hidden by the electron beam emittance and therefore not significant.

The finite length oscillations are an extremely sensitive measure for the constant dipole field. Returning to the spectrum shown in Fig. 2, a similar simulation with artificial field maps as carried out for the 16 mm case reveals a constant dipole contribution of 1.75 mT which is in very good agreement with the estimation from the integrated field map.

## CONCLUSIONS

On-axis and angularly resolved spectra of the ANKA superconductive undulator SCU14 were measured and compared to simulations based on the magnetic field maps of the SCU14. In general, the results of the measurements are in good agreement with the theoretical expectations. Within the limits imposed by the electron beam emittance it is possible to identify the effect of particular systematic field errors present in the SCU14. Especially the existence of a small constant dipole contribution exhibited by the field maps was verified by the analysis of the radiation spectra.

## REFERENCES

[1] Robert Rossmanith et al. A year's experience with a superconducting undulator in the storage ring ANKA. In *Proceedings of EPAC, Edinburgh, Scotland*, pages 3571–3573, 2006.

[2] S. Casalbuoni et al. Beam heat load and pressure rise in a cold vacuum chamber. *Physical Review Special Topics Accelerators and Beams*, 10:093202, 2007.

[3] A. Bernhard et al. Magnetic field properties of the ANKA superconductive undulator. *Nuclear Instruments and Methods in Physics Research A*, submitted, 2009.

[4] P. Wesolowski. private communication, 2009.

[5] T. Tanaka and H. Kitamura. Spectra — a synchrotron radiation calculation code. http://radiant.harima.riken.go.jp/spectra/.

[6] M. Homscheidt. Master's thesis, University of Karlsruhe, 1999.