

MEASUREMENTS OF THE LATTICE MODIFICATIONS FOR THE CRYOGENIC UNDULATOR CPMU-17

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Abstract

A 2 mrad-canted double undulator system is in preparation as the wide energy range light source for the Energy Material in-situ Laboratory EMIL at the HZB storage ring BESSY II. The cryogenic undulator CPMU-17 is the hard X-ray device of the double undulator system. The soft X-ray undulator UE-48 is of the APPLE II type. It was installed and commissioned a few months ago, whereas the CPMU-17 is under fabrication. The CPMU-17 will employ a minimum magnetic gap of 5.5mm. Including a CuNi-foil for RF-shielding and geometric tolerances the free aperture is planned to be 5.0 mm. The BESSY II lattice has been modified locally in order to cope with the small gap device. The adapted betatron functions with a shifted vertical beam waist were measured and fitted with LOCO. The new optics agrees with the predicted performance. The free aperture at the installation place of the CPMU-17 was measured with four vertical scrapers. It is compatible with the projected minimum undulator gap. Finally, the measured injection efficiency with the new EMIL optics switched on is compatible with top-up operation (injection efficiency $\geq 90\%$).

EMIL-PROJECT

The new dedicated Energy Material in-situ Laboratory EMIL at the HZB storage ring BESSY II is close to completion. The laboratory permits cutting-edge research in the fields of energy conversion and energy storage including photovoltaic applications and photo-electrochemical processes. The key point for an efficient research environment is the combination of i) high brightness sources, i.e. undulators in a 3rd generation storage ring and high throughput monochromators, ii) sophisticated laboratories for spectroscopic analysis such as PES, PEEM, HAXPES, XES, XAS, XRF, XRD and iii) industry like sample preparation with in-vacuum transfer lines to the analysis chambers. This unique arrangement with in-system, in-situ and in-operando capabilities guarantees a fast feedback between intermediate processing steps and sophisticated analytics. A detailed description of the EMIL layout is given in [1].

The production and analysis tools are under commissioning in the new EMIL building, and the beamlines and monochromators are being assembled. Here, we concentrate on the undulators. Two canted undulators deliver photons over a wide energy range:

Soft-X-rays with variable polarization are generated from an APPLE II with the period length $\lambda_0 = 48\text{ mm}$ (UE-48) and hard-X-rays originate from a cryogenic undulator with $\lambda_0 = 17\text{ mm}$ (CPMU-17) [2].

STATUS OF STRAIGHT SECTION AND THE CANTED UNDULATOR SYSTEM

The BESSY II insertion device chambers have a vertical aperture of 10 mm whereas the short period small-gap undulator CPMU-17 requires a magnetic gap of 5.5 mm. A fatal beam scraping with the magnetic structure is excluded with a local lattice modification with a small vertical betatron function.

The straight section has been prepared for the canted undulator system. The current status is shown in Figure 1. An additional quadrupole is installed at the center of the straight section. This quadrupole in combination with a specific de-tuning of the neighbouring quadrupoles shifts the vertical beam waist to the center of the cryogenically cooled undulator and reduces the maximum vertical betatron function within the CPMU-17 from 4.87m to 1.89m.

A replacement chamber incorporating four vertical scrapers at the hardware edges of the future CPMU-17 was installed to provide tools for a detailed analysis of the new optics. These scrapers were used for vertical aperture measurements.

The new quadrupole includes an electromagnetic horizontal 2 mrad-steerer for the separation of the undulator radiation beams. Additionally, 0.1 mrad horizontal and vertical steerers are included in the magnet.

The UE48-APPLE undulator has been installed in January, 2016. During commissioning feed forward tables for kick and tune compensation were established. A system of six Fe-free correction coils is used for the compensation of residual horizontal and vertical kicks. The UE48 is ready for operation.

The liquid nitrogen supply for the CPMU-17 is already installed and connected to the cryocooler in the experimental hall.

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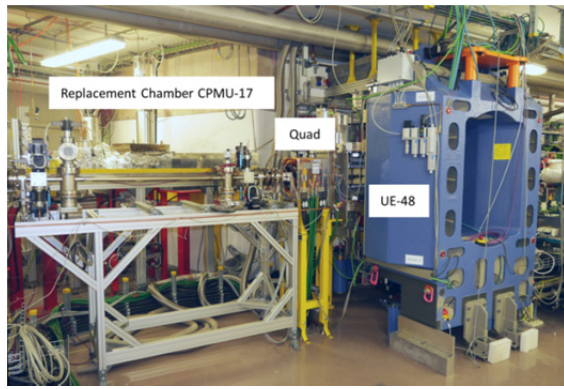


Figure 1: Current status of straight section of the canted undulator system. Left: replacement chamber with four vertical scrapers; center: additional quadrupole of EMIL optics; right: UE48 APPLE II.

VERIFICATION OF THE NEW LATTICE

The so-called EMIL optics is characterized by a local longitudinal shift of the vertical beam waist to the anticipated center of the CPMU-17 undulator. The EMIL-optics has been simulated already in 2012 [3]. The detuning of the existing neighbouring quadrupoles and the setting of the additional quadrupole in the center of the straight are taken from the simulations. The beam orbit has been measured and the betatron functions have been derived via a LOCO-fitting. The results, after one additional iteration are close to prediction (Figure 2). A slight betatron function asymmetry around the CPMU-17 center is observed.

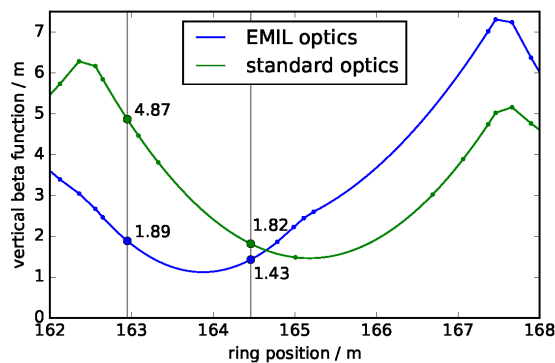


Figure 2: Measured EMIL-optics as fitted with LOCO.

VERTICAL APERTURE MEASUREMENT

Four scrapers are utilized for a vertical aperture measurement at the critical points. They are located in distances of ±756 mm from the undulator center mimicking the undulator structure hard edge. With a beam current of 20 mA each scraper was driven individually into the beam and the lifetime was extracted from a commercially available DC parametric current transformer (PCT, Bergoz) [4,5]. Figure 3 depicts a representative measurement which correlates the lifetime to a linear but uncalibrated scraper reading. The relative scraper position with respect to the electron beam was derived from a fit of the raw data.

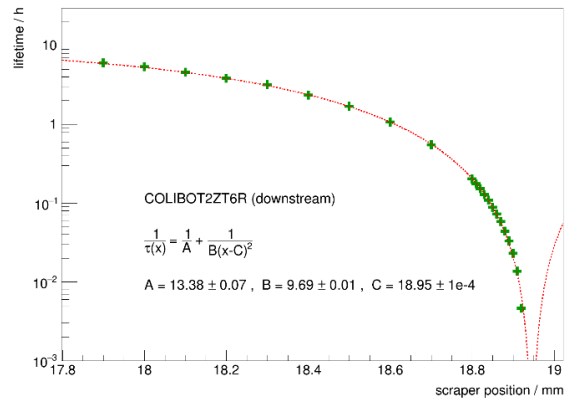


Figure 3: Scraper calibration (for details see text).

The data were fitted with the function given in the graph. The three fitting parameters A, B and C represent i) the lifetime with scraper moved out, ii) a parameter, which is inversely proportional to the betatron function and iii) the electron beam position.

The fitting results of the four scraper measurements are summarized in Figure 4. For a proper comparison of the fitted B-values the parameters A and C are set to A = 15 h and C = 0 mm. The results for the two upstream and the two downstream scrapers are identical among each other. Upstream and downstream scrapers yield slightly different B-values (Table 1). The asymmetry is consistent with the asymmetry of the vertical betatron function as derived from the LOCO fit (Figure 2).

Table 1: Fitted B-values in s/mm² and Vertical Beta Function in m (Figure 2)

| | upstream | downstream | comparison |
|---------|----------|------------|----------------|
| top | 7.11 | 9.11 | |
| bottom | 7.34 | 9.69 | |
| average | 7.23 | 9.40 | ratio = 0.77 |
| beta_y | 1.89 | 1.43 | 1/ratio = 0.76 |

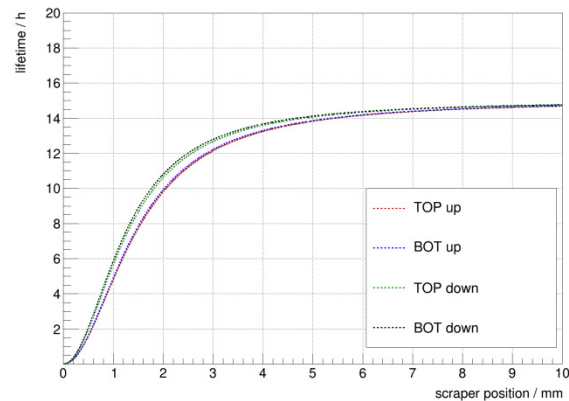


Figure 4: Fitting function with A=15h and C=0mm for four individual scraper measurements. The slope of the graphs at small scraper positions is a measure of the vertical betatron function.

In a second measurement the calibrated scrapers were moved individually over a wider range until shadowing effects appear. These measurements were performed at a low current of about 2 mA with an artificially vertically excited beam. Thus, no changes are expected for high current beams. The lifetime was extracted from a windowless Si-photodiode with linear response operated by the Physikalisch, Technische Bundesanstalt (PTB) [4,5]. The diode has a better signal to noise ratio as compared to the current monitor which is beneficial for the measurements of long lifetimes at low currents. All scrapers introduce a clear shadowing at individual absolute positions between 2 and 2.5 mm. The results are summarized in form of the lifetime dependence upon the free vertical aperture (Figure 5). A common lifetime was fitted to all scraper data points beyond the shadowing limit of 2.5 mm. This lifetime was used for a fitting of the individual scraper data with a Heaviside function. Within the error bars no upstream / downstream asymmetry is observed.

Within an error of $\pm 0.02\text{mm}$ a shadowing occurs at the positions: upstream top: 2.26 mm; upstream bottom: 2.28 mm; downstream top: 2.20 mm and downstream bottom: 2.34 mm. Thus, the free aperture A is symmetric in beam direction around the undulator center with:

$$A_{US} = 2.26\text{mm} + 2.28\text{mm} = 4.54\text{mm} \text{ (upstream)}$$

$$A_{DS} = 2.20\text{mm} + 2.32\text{mm} = 4.52\text{mm} \text{ (downstream)}$$

Consequently, with a correct alignment (centering) of the undulator no beam scraping is expected for the projected vertical stay clear of 5 mm.

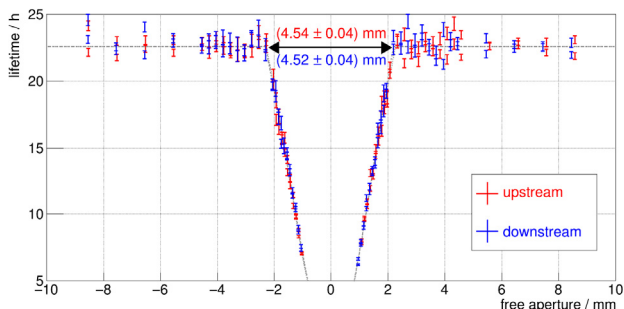


Figure 5: Lifetime measurement with vertical scrapers.

The results of Figure 5 in combination with the asymmetry in Figure 2 and Figure 4 will be subject of future studies.

The injection efficiency with scrapers moved into the halo has been checked in an independent experiment where all four scrapers were moved simultaneously in and out. This preliminary experiment has been performed at low current (a few mA), with all permanent magnet undulators opened to 100 mm gap and all superconducting insertion devices switched off. Finite injection efficiency (10 %) is observed for a free aperture of 1.6 mm. With an aperture of 3.2 mm already 90 % efficiency is achieved, which is sufficient for top-up operation.

UNDULATOR E-BEAM INTERACTION

The gap (shift) dependent tune shift of the undulators will be compensated feedforward mode, as usual at HZB. The effect of the CPMU-17 is very small since it scales linearly with $1/\lambda_0^2$.

The residual kicks of the UE-48 are corrected with Fe-free air coils as depicted in Figure 6 which generates 0.3 Tmm / 3 A at a distance of 22 mm (Figure 7).



Figure 6: 3-coils set for horizontal and vertical beam steering. One unit is mounted above, one below the beam.

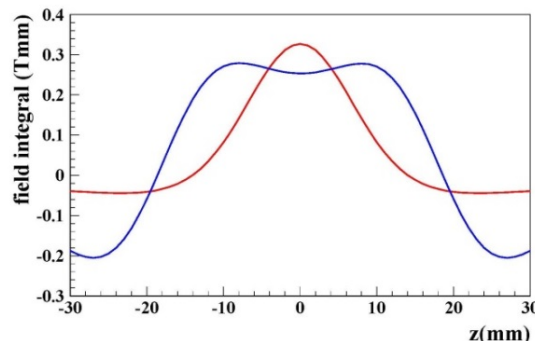


Figure 7: Vertical (red) and horizontal (blue) field integrals of the complete UE-48 correction coil system (six coils) at a gap of 22 mm between the 3-coils sets.

The UE-48 coils are adapted to the CPMU-17 geometry (Figure 8). They are located close to the undulator ends above and below the flexible tapers. The height of the water cooled coils are designed to guarantee horizontal and vertical field integrals 0.3 Tmm / 3 A.

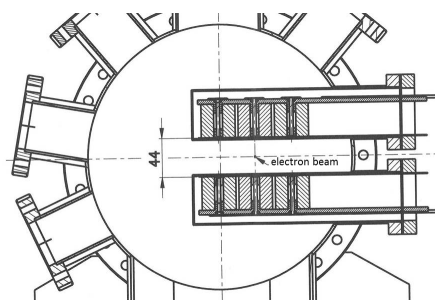


Figure 8: Cut of the CPMU-17 chamber with correction coils. The e-beam and the magnet structure are displaced to the center because for measurement and tuning an in-vacuum hallprobe bench will installed beneath the magnet girder.

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