

STATUS OF THE CRYOGENIC UNDULATOR CPMU-17 FOR EMIL AT BESSY II / HZB

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Abstract

The CPMU-17 is the hard X-ray radiation source of a canted double undulator system for the Energy Materials In-situ Laboratory EMIL at BESSY II [1]. Various ambitious concepts are realized in this undulator such as Dy-hardened PrFeB-magnets, direct liquid Nitrogen cooling, dual loop feedback gap drive based on an optical micrometer and a low permeability stainless steel In-Vacuum(IV)-girder without keepers. The magnets are sorted according to Helmholtz coil and stretched wire data. Reproducibility and accuracy measurements of two IV-measurement tools needed for the CPMU-17 are presented: an IV-Hall probe bench and an IV-Moving Wire.

THE UNDULATOR CPMU-17

The basic parameter set of the cryogenically cooled permanent magnet undulator is documented in [2].

Field Tuning Strategy

The field quality of the magnetic structure will be tuned by means of several procedures: i) each girder base plate carries four comb shaped gauges for a precise positioning of the magnets and poles. The two combs on each side must be positioned longitudinally to an accuracy of 10 μ m. This is achieved via CMM measurements of the mounted combs and the insertion of specifically machined keys, which compensate for geometric fabrication tolerances; ii) all magnets are measured in an automated Helmholtz coil; iii) additionally, the side facing the electron beam is moved along a fixed, 0.5 m long wire, for the characterization of the inhomogeneities; iv) these data are used in a simulated annealing code, which optimizes for minimum trajectory errors and low phase error. The sorting is done for a pure permanent magnet structure without poles, hence, minor deviations from the sorting results are expected. However, the starting point for shimming is improved as compared to an unsorted structure; v) the trajectory straightness is shimmed with a pole height adjustment via a replacement of the pole clamps; vi) residual field integrals are shimmed with in-vacuum magic fingers (Fig. 1), which are similar to the magic fingers usually used for all BESSY II-undulators [3]; vii) gap dependent dipole errors are compensated with air coils at the flexible taper section.

Endpole Compensation

Triggered by a modification of magnet and pole clamps, the endpole termination was re-designed. The four tuning parameters are: the vertical sizes of two end magnets and the vertical positions of these magnets. With

an appropriate choice, a field integral variation over the gap for one endpole can be as low as 0.035 Tmm, which is well within the tuning range of the air dipole coils at either end, which provide field integrals of ± 0.3 Tmm in both planes at 3 A (Fig. 2 and Fig. 3).

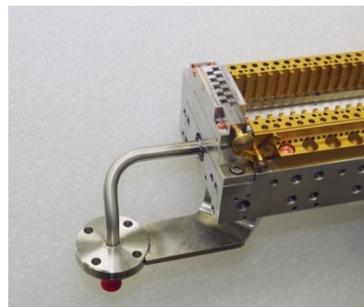


Figure 1: Magic fingers at the four magnet girder ends. Each slot is filled with a transversally quadratic permanent magnet of a specific thickness.

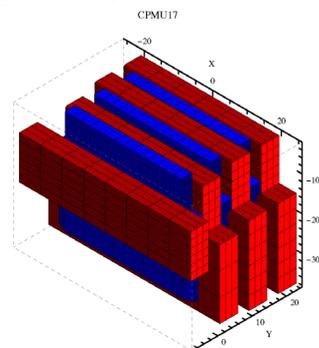


Figure 2: Endpole configuration of the CPMU-17.

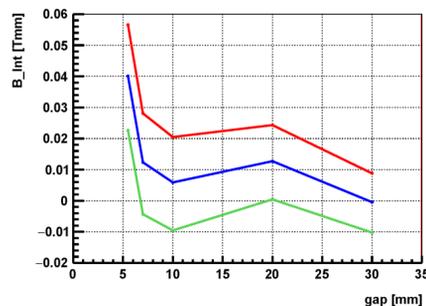


Figure 3: 1st vertical field integrals versus gap of one end section (symmetric structure). Green: nominal vertical position of the last magnet. Blue, red: last magnet is moved by 0.1 and 0.2mm towards the gap.

Optical Windows for Gap Measurement

The magnetic gap is measured with a Keyence optical micrometer. A light band with a height of 40 mm is generated in the transmitter, passed through the 1st window

into the vacuum, scraped with two blades close to the electron beam and transferred through a 2nd window to the receiver. The windows must have a high quality in order not to disturb the required measurement accuracy of $\pm 1.5 \mu\text{m}$. Earlier measurements, which were based on high quality parallel glass plates of 20 mm thickness [4], yielded an accuracy of $\pm 1.5 \mu\text{m}$. However, there is no cost efficient technique to weld the glass plate into a CF-flange. Thus, the optical quality of commercial windows, which are already prepared for welding, was characterized in a test setup in air. Two windows and the optical micrometer system were positioned in the design geometry. Two apertures were moved over a range of 3-53mm mimicking the gap movement. The aperture height was measured over several opening and closing cycles with the optical micrometer and with a reference system, a Heidenhain encoder ULS300. The differences are plotted in Fig. 4. The windows have a non-linear response of up to $23 \mu\text{m}$. Nevertheless, the reproducibility is within $\pm 1.5 \mu\text{m}$, which is acceptable in combination with a calibration table.

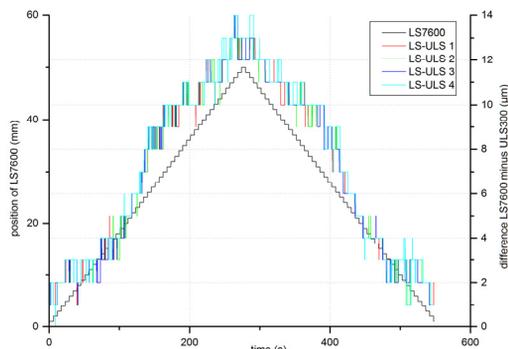


Figure 4: Gaps as measured with an optical micrometer and an ULS300 encoder over the whole gap range with two commercial optical windows.

First Results of the CPMU-17

The precision of the girder geometry defines the initial quality of the magnetic structure. The eight combs of two girders give the longitudinal pole position and the pole height. The combs were adjusted longitudinally with an accuracy of $10 \mu\text{m}$ (Fig. 5).

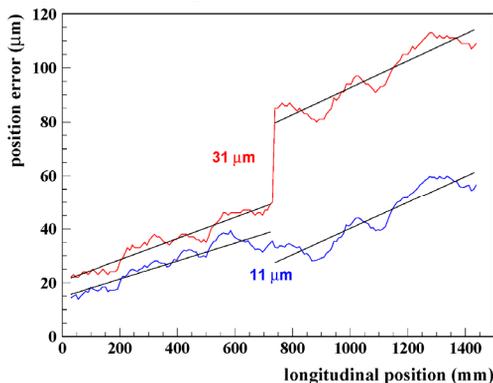


Figure 5: Longitudinal tooth position of two combs before (red) and after (blue) relative adjustment. The fitted slope is a measure for the fabrication temperature.

Preliminary Hall probe data are plotted in Fig. 6. Generally, the prediction from sorting and measurements agree, with an exception within $0 \text{ mm} < x < 270 \text{ mm}$ and $-5 \text{ mm} < z < 20 \text{ mm}$. The reason for this behaviour is currently under investigation.

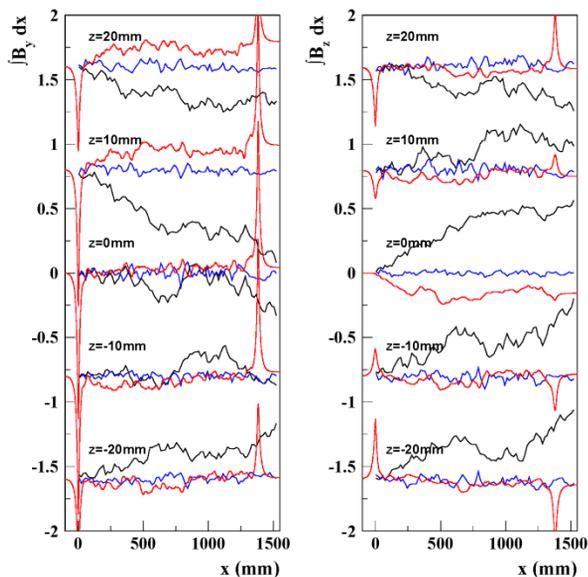


Figure 6: 1st field integrals of half-period filtered data of the lower un-shimmed girder with magnets only (poles not inserted, yet). Black: before magnet sorting; blue prediction from sorting; red: measurement. For better visibility, the data sets at different transverse positions z are displaced vertically.

IV-MEASUREMENT SYSTEMS FOR THE CPMU-17 AND OTHER DEVICES

The CPMU17 will be measured with two new in-vacuum measurement systems, a Hall probe bench (IV-HPB) and a moving wire system (IV-MWS). Both tools demonstrate a high quality which is sufficient for the characterization of modern short period in-vacuum devices such as the CPMU-17.

In-Vacuum Hall Probe Bench

The reproducibility of the system was thoroughly tested via on-axis scans with the 2nd 9mm-period length, 10-periods prototype, which was built at HZB [4]. The short period length yields a high field gradient, longitudinally and vertically, which is desirable for the commissioning of the bench. For better visibility the measured data were pre-processed via integration and half period filtering (removal of the oscillatory part). Typically, five data sets were averaged and the difference of the five scans to this average was analysed (Fig. 7). The differences are below 0.001 Tmm rms. Scaling this number linearly to a 2 m device we get a conservative number below 0.02 Tmm rms. In reality the number will be even smaller, because the field integral variation behaves more like a random walk (scaling with $\sqrt{\# \text{ of periods}}$).

These excellent results rely heavily on a 3-axis laser interferometer, which is used for a yaw- and pitch-correction of the Hall probe-slide. The residuals after angular correction are about $30 \mu\text{rad}$ rms (100-200 μrad uncorrected). The yaw correction, which compensates for a horizontal bending of the measurement bench, introduces an unintentional longitudinal motion of the Hall probe by a few micrometer. This effect must be compensated via a recalibration of the position, to achieve the reproducibility as plotted in Fig. 7, bottom. Since the yaw-correction is not smooth and occurs at unpredictable positions (Fig. 8, bottom), initially, large field integral changes occur at each correction step (Fig. 8, top). The position correction reduces this effect by an order of magnitude (Fig. 7, bottom in comparison to Fig 8, top).

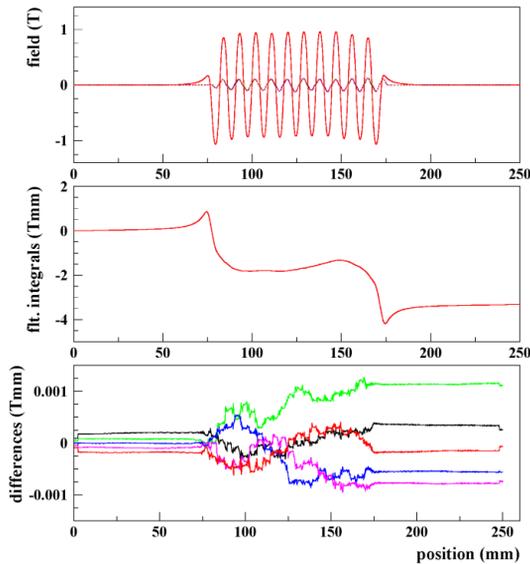


Figure 7: Results of five scans with yaw-feedback switched on and z-axis correction activated. Top: vertical (solid) and horizontal fields (dotted); center: filtered 1st field integrals; bottom: differences of five data sets with respect to the averaged data.

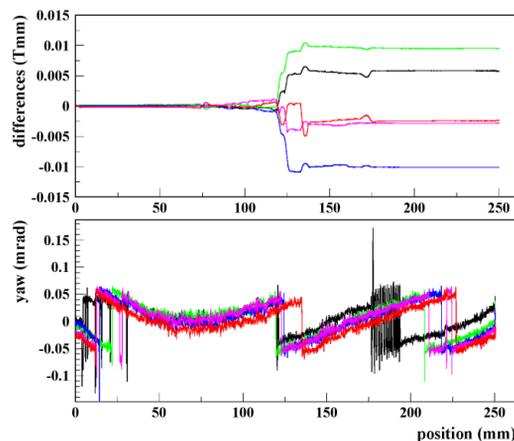


Figure 8: Results with yaw-feedback switched on. Top: Filtered 1st field integrals without position correction; bottom: yaw-angles as measured with the laser interferometer.

In-Vacuum Moving Wire

The in-vacuum moving wire system has been commissioned and first data has been taken under vacuum conditions with a 250mm long piece of an old APPLE II magnet row. The noise is dominated by wire vibrations, which is obvious from the increase with decreasing step size. Two sets of measurements with steps of 2mm and 1mm are shown in Fig. 9. The measurement time intervals are 200ms and 100ms, respectively. A delay of 1s is introduced between each measurement step. The magnet structure is placed at the place of largest vibration amplitude.

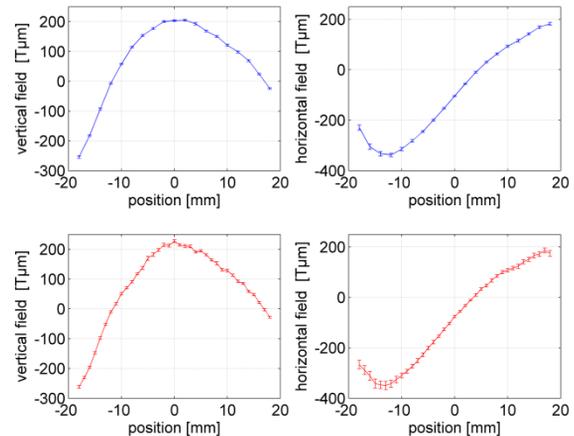


Figure 9: Field integrals as measured with the IV-MWS with a 0.125mm CuBe-wire with a total length of 2000mm. Top: 2 mm steps; bottom: 1 mm steps.

Table 1 summarizes the results. Two points are worth mentioning: the measurements are performed with a single wire, and the rms-values are given for single measurements (no averaging of scans).

Table 1: Measurement Error of In-Vacuum Moving Wire

Condition	Step size	$\int B_y \cdot dx$	$\int B_z \cdot dx$
In air	2mm	1.6 T μm	2.3 T μm
In vacuum	2mm	2.9 T μm	5.0 T μm
In vacuum	1mm	4.2 T μm	8.7 T μm

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