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# CORRECTING THE MAGNETIC FIELD OFFSETS INSIDE THE UNDULATORS OF THE EuXFEL USING THE K-MONOCHROMATOR

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*Abstract*

Hard X-ray free-electron lasers (XFELs) generate intense coherent X-ray beams by passing electrons through undulators, i.e. very long periodic magnet structures, which extend over about two hundred meters [1]. A crucial condition for the lasing process is the spatial overlap of the electrons with the electromagnetic field. Well established electron beam-based procedures allow to find a straight trajectory for the electrons defined by the beam position monitors (BPM) between the undulators. A bending of the trajectory in between the BPMs cannot be seen by these methods. A general field offset inside the undulators has the effect that the synchrotron radiation is emitted at a different angle at the beginning and the end of the undulator which can result in a degradation of the FEL-gain especially for very short wavelengths. We report on how the spectral and spatial characteristics of the monochromatized radiation of a single undulator can be used to minimize the field offset in situ with the help of correction coils.

## HANDLING THE MAGNETIC FIELD OFFSET

Several survey campaigns have been conducted to measure the ambient field in the tunnel, at different stages of the construction phase. Only small differences have been observed in the ambient magnetic field through construction. In all three SASE average ambient vertical fields of 50 µT and horizontal of 15 µT for SASE1 and SASE2 and 20 µT for SASE3 have been observed [2-4]. However, after installation of all equipment in the tunnel the situation might be different.

In order to minimize the field offset in the undulators the magnetic characterization and tuning has been done in the same ambient field as in the tunnel. This has been realized by the installation of Helmholtz coils in the measurement hutches to adjust the ambient field.

For the compensation of residual fields inside the undulators after installation in the tunnel a correction system has been implemented. Two current windings have been installed along the undulator chambers and connected to power supplies which allow to superimpose a vertical magnetic field of up to 400 µT [5, 6] (see Fig. 1).

Up to now the coils to compensate for the vertical ambient field have not been used.

The SASE optimization process is already delivering excellent results in term of pulse energies in all three SASE undulator lines. In order to further improve the signal, we decided to measure the ambient magnetic field, and eventually correct its vertical component by means of the TWCS shown in Fig. 1.

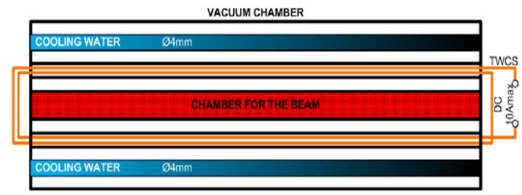


Figure 1: Top View - schematics of the EuXFEL undulator chamber with the beam pipe, the cooling channels and the installed two wire correction system (TWCS) [5]. The TWCS can correct the vertical ambient magnetic field.

## MEASUREMENT PRINCIPLE

For electron beam-based techniques there is the general problem that it cannot be distinguished whether a deflection is produced over the length on an undulator or from end kicks. Therefore, we were trying to use the properties of the undulator radiation.

First, we looked into the variation of the energy spectrum and in fact one observes an asymmetry with rising field offset, but the sensitivity was not strong enough to get the desired accuracy. Therefore, we started to investigate the spatial distribution of the undulator radiation which shows a very clear response on the magnetic field offset when looking at the ring structure obtained from the monochromatized radiation. (see Fig. 2)

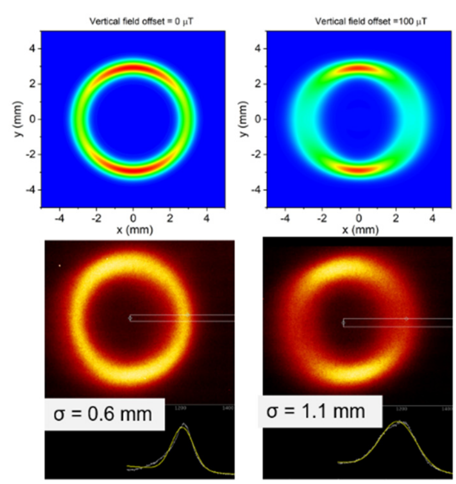


Figure 2: Spatial distribution of the monochromatized undulator radiation for a pure undulator field (left) and with a superimposed vertical magnetic field of 100 µT (right). The upper plots are the results of a simulation with SPECTRA [8] while the lower plots are measurements with the K-monochromator including the vertical projection of the intensity within the drawn rectangle and the gaussian fit to this distribution. (electron energy = 14 GeV, 1$^{st}$ harmonic at 9.15 keV, monochromator set to 8.91 keV).

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### *The Monochromator*

To observe the ring structure of the undulator radiation we use the K-Mono which is installed behind the undulators (see Fig. 3). With the sensitive GOS scintillator ($Gd_2O_2S{:}Pr$) we typically use a train of 10-30 bunches to get a good signal to noise ratio [7].

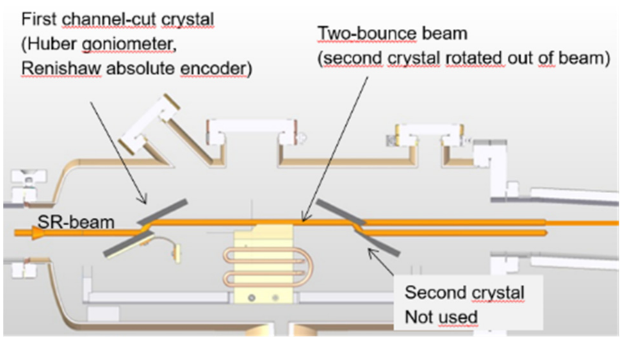


Figure 3: Schematic of the K-Mono. The monochromator is placed about 160 m behind the undulator section. For these measurements we use the “two bounce” beam which hits a GOS screen and is observed by the imager with a 14.3 µm pixel size.

## THE MEASUREMENT

The absolute width of the rings can vary due to various effects like beam size, energy spread etc., why we are scanning the vertical magnetic field with the TWCS to get a clear measurement. The simulations with SPECTRA show that the horizontal width of the rings depends quadratically on the field offset and therefore at the minimum the TWCS compensates ideally the present field offset. This is confirmed by the measurements shown in Fig. 4. Since the field offset is the only parameter which is changed during the measurement the result does not depend on other contributions.

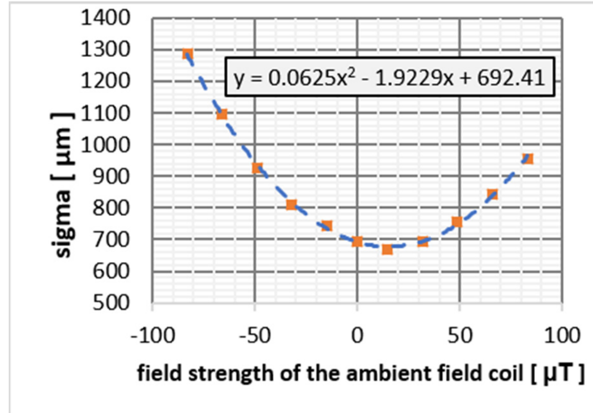


Figure 4: Field offset scan at SASE2, cell 23 with the quadratic fit. At the minimum the field offset is perfectly compensated by the ambient field coil (TWCS).

After development of an automatic procedure for this measurement the field offsets of all of the 35 undulators of the SASE2 undulator section have been measured. For some undulators the measurement has been repeated to investigate the reproducibility (brackets). The data are shown in Fig. 5 leading to the following results:

- The first observation is that the field offsets in all undulators are below ~25 µT. According to preliminary estimations these distortions are too small to have a larger impact on the lasing performance.
- The strength of the vertical field offset is not constant but varies significantly.
- The orange and blue bars show the results when fitting the left and right side of the ring width separately. Ideally the two minima should appear at the same correction field, which is often the case but not always. This is an observation we will try to understand better during following measurements.

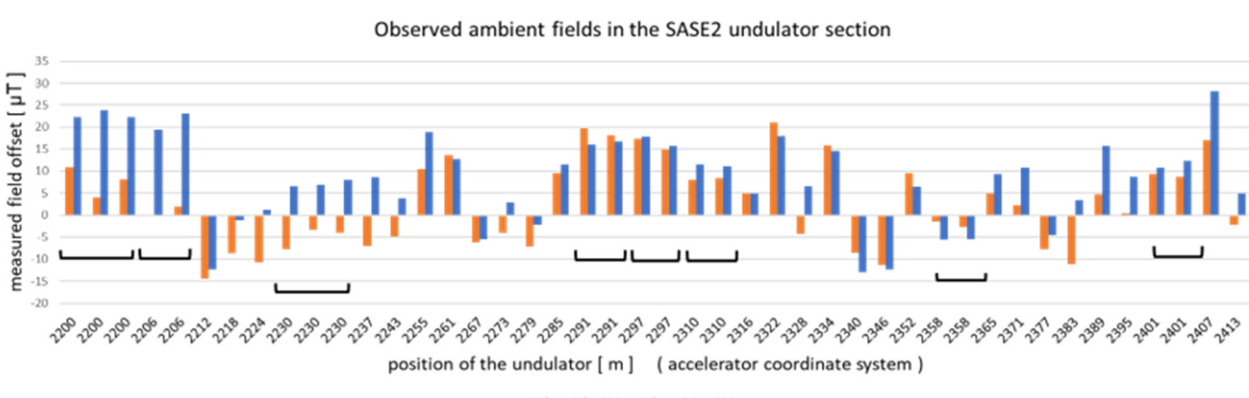


Figure 5: The blue and orange bars are the results obtained for the left and right side of the rings. While both sides give a similar result for quite a number of undulators, this is not the case for others. The reason is not clear yet and further investigation is needed. The measurements have been done with an electron energy of 14 GeV and undulators set to 9.15 keV, which corresponds to an undulator gap of 13.5 mm.

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- During the measurement we recognised a geometrical problem. Since the radiation has to pass the complete 220 m long beam pipe we had to reduce the size of the rings to measure the first undulators in the section. This reduces the precision of this measurement and might be part of the explanation for the last point.

### *Gap Dependence*

All the measurements in Fig. 5 have been done with and undulator gap of 13.5 mm. For four undulators we repeated the measurement also for a gap of 11.7 mm and 15.6 mm (Fig. 6). The conclusion is that the field offsets generally depend on the gap of the undulators. In one case the offsets stay constant while it goes negative with rising gap in two cases and it went positive in one case. Therefore, if a correction is needed at different photon energies one has to measure this gap dependence for all involved undulators. Further investigations to better understand this observation are foreseen.

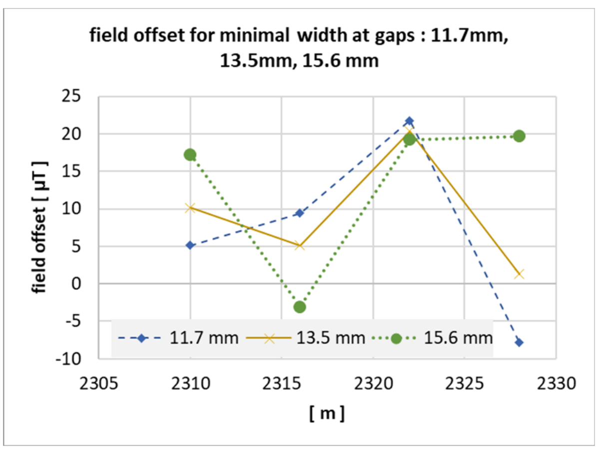


Figure 6: Measured field offsets at different gaps for 4 different undulators.

## CONCLUSION

A method has been developed to measure in situ the vertical magnetic field offset inside the undulators at the EuXFEL using the installed correction windings and a monochromator.

We are using the so-called K-Mono rings which appear as the spatial distribution of the undulator radiation at an energy slightly below the first harmonic.

The precision of this method still has to be investigated - from the measurements so far it should be better than 10 µT.

Further studies are planned to further improve the method, investigate the observed effects and measure also the second high-energy beamline SASE1.

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