AUTOMATION OF THE UNDULATOR MIDDLE PLANE ALIGNMENT RELATIVE TO THE ELECTRON BEAM POSITION USING THE K-MONOCHROMATOR

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Abstract / Introduction

The correct K value of an undulator is an important parameter to achieve lasing conditions at free electron lasers. The accuracy of the installation of the undulator in the tunnel is limited by the accuracy of the instruments used in surveying. Moreover, the position of the electron beam also varies depending on its alignment. Another source of misalignment is ground movement and the resulting change in the position of the tunnel. All this can lead to misalignment of the electron beam position relative to the center of the undulator gap up to several hundred microns. That, in turn, will lead to a deviation of the ΔK/K parameter several times higher than the tolerance requirement. An automated method of aligning the middle plane of the undulator, using a K-monochromator, was developed and used at European XFEL. Details of the method are described in this article. The results of the K value measurements are discussed.

Reqiuerments for undulator systems

One prerequisite for achieving lasing is the tuning of the K-value of all undulator segments to a very high precision. The undulator segments are characterized by the K-parameter: $K = \frac{eB\lambda_u}{2\pi m_e c}$, where B is the effective magnetic field and λ_u is the undulator period.

From FEL tolerance calculations, it can be shown that the relative error in the produced wavelength must be smaller than the Pierce parameter ρ. ρ is a fundamental scaling parameter and gives a measure of the exponential gain and saturated efficiency of a high-gain FEL, with typical values in the X-ray regime of $10^{-4} \le \rho \le 10^{-3}$ [4, 5]. The error in K for the given error in λ at 1 Å (~12 keV photon energy) is approximately $3 \cdot 10^{-4}$ and determines the required K-measurement accuracy.

K value measurement methods

There are several methods for K-tuning, phase matching, and trajectory alignment for which the K-mono can be used [4, 6, 7]. Here we have used the K-mono with SR-imager for observing the spatial profile of the spontaneous radiation of single undulator segments [3]. During our tests this appeared to be the fastest method.

When tuning the K-mono to photon energies slightly below the resonant energy of the undulator segments, donut-like rings appear, as the divergence angle of the spontaneous radiation depends on the photon energy and the off-axis spectrum gets 'red-shifted'. The diameters of the rings depend on gap settings, e-beam energy, detuning factor, and distance to the undulator segment. With these parameters known with high accuracy, the K parameter can be determined directly from the ring diameter, which is a measure for the observation angle ϴ in the undulator equation:

$$\lambda_n = \frac{\lambda_u}{2n\gamma^2}\left(1 + \frac{K^2}{2} + \theta^2\gamma^2\right) \text{ (1).}$$

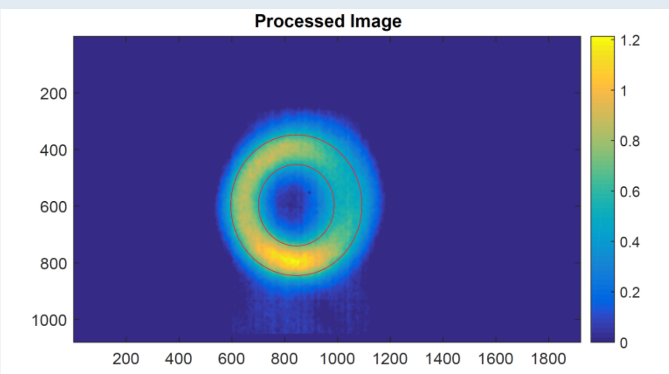

Figure 1: Online ring fitting

For relative K tuning of the segments it is sufficient to tune to the same spatial profile by taking into account the geometrical factor of different distance to the screen, since all other parameters are equal for the segments. For the SASE1 undulator we have performed three complete scans where segment by segment was closed to the nominal K-value for 9.3 keV photon energy while all other segments were opened. The fitting algorithm was applied to the images to determine the ring diameters and subsequently the K-values (Fig. 1). Two independent measurements (repeated after two hours) were performed in July in order to estimate the measurement error, including drifts of e-beam energy and position as well as electronic noise. This scan was repeated in October after the vertical alignment of cell 8.

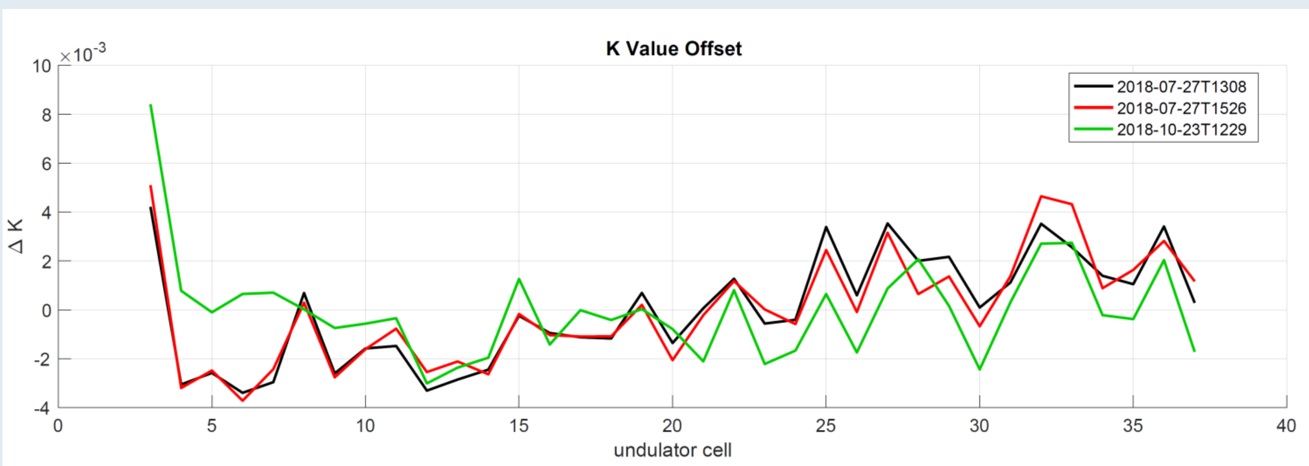

Figure 2: K value measurement results for SASE1 undulator system

These measurements show that the RMS value of ΔK/K for the entire SASE1 system, without middle plane adjustment and excluding applied linear taper, is ~ $4.3 \cdot 10^{-4}$.

Undulator middle plane control

The gap of the undulator is controlled by four servo motors. Two motors are controlling the upper strong back and the other two motors are controlling the lower strong back. The control system of the undulator is done by means of Beckhoff TwinCAT. The feedback value of the gap could be obtained either from the rotary encoders installed on the motors, or from two linear encoders, located on both sides of the undulator and directly measuring the gap between the magnet structures (see Fig. 3). For the standard operation the linear encoders are used for the undulator gap feedback. It is done in the following way. The linear encoders are measuring the distance between the magnet structures. The PLC is reading this value with 1 kHz frequency. The difference between the gap value provided by the rotary encoders and the linear encoders is measured during a PLC cycle. This information is used for feedforward correction to the rotary encoders in the sequencing PLC cycle. Thus, it is possible to achieve the truth-measured gap value with a delay of one millisecond.

Similarly, the vertical offset of the middle plane of the undulator gap is realized. Depending from the direction, the vertical offset is added or subtracted as an additional correction value to the rotary encoder values.

The Distributed Object-Oriented Control System Framework (DOOCS) is used for the control of the accelerator at European XFEL. Therefore, the interface to DOOCS is provided for the vertical offset scan (see Fig. 4).

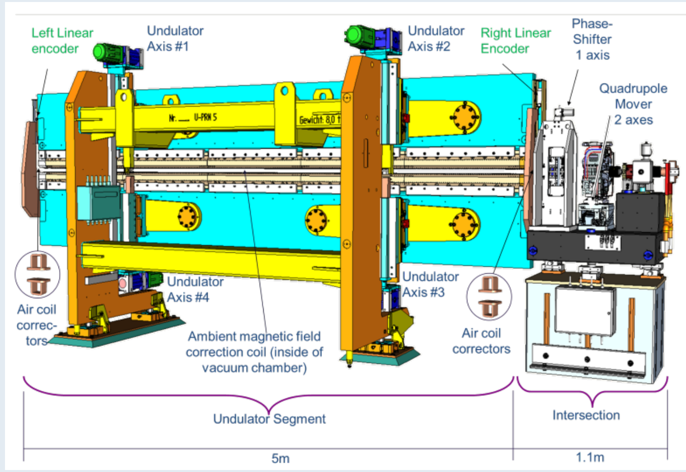

Figure 3: Undulator cell, consisting of undulator segment and intersection.

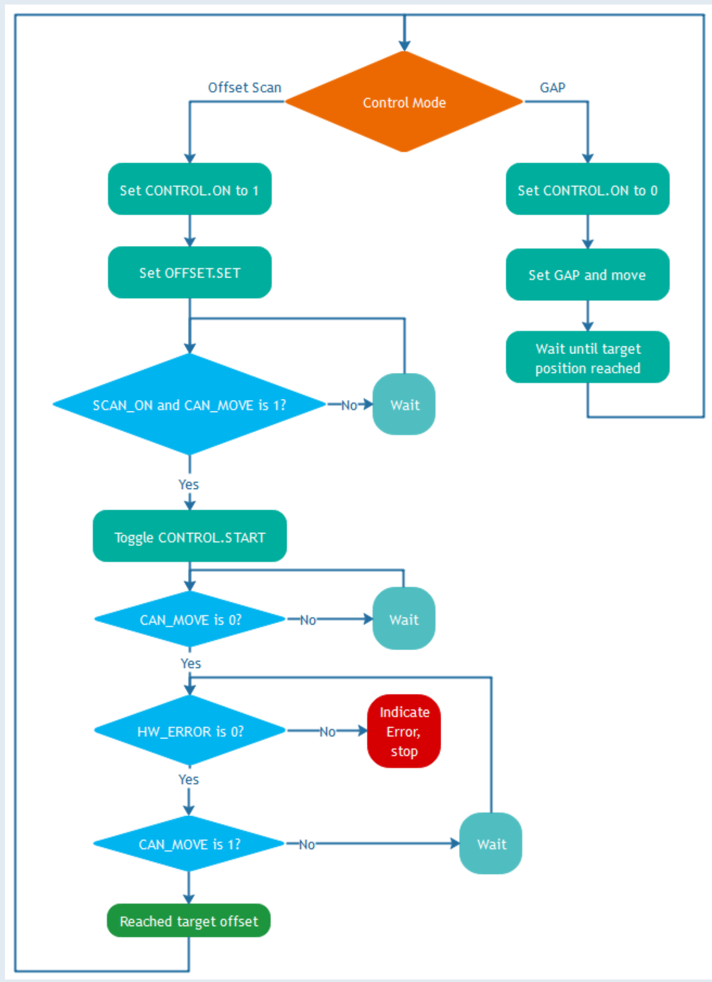

Figure 4: The flow chart of the undulator middle plane scan program.

Results

The vertical magnetic center of the undulator in SASE1 cell 8 was measured, since from previous measurements it was seen that the resonant wavelength is different from the required one.

The variation of K-parameter along y can be calculated using Eq. (2), using SASE1 undulator period:

$$\frac{\Delta K}{K} = \frac{1}{2}\left(\frac{2\pi y}{\lambda_u}\right)^2, \ y = \frac{\lambda_u}{2\pi}\sqrt{2 \cdot \frac{\Delta K}{K}}. \text{ (2).}$$

With the measured data and the best-fit curves (see Fig. 5) we could determine the best vertical undulator position to -306 µm offset

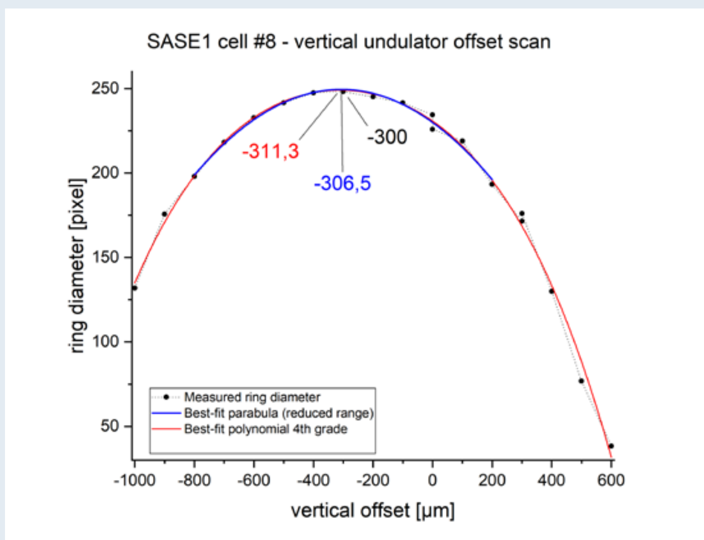

Figure 5: Ring radius versus vertical undulator offset

Conclusions

The correct value of the K parameter is one of the most important conditions for the operation of a free electron laser. There are many sources of errors of the resonant radiation of the undulator. These include deviations of the energy, position and angle of the electron beam (1), as well as the accuracy of the gap positioning or the local temperature of the undulator magnetic structures. Nevertheless, the results of measuring the K value, for example, in SASE1 showed that even without additional adjustment of the vertical position of the undulators middle plane, the RMS value of ΔK/K is very close to the Pierce parameter.

First automated procedures were used to measure the K value for all 35 segments of the SASE1 and SASE2 undulators and acquire a full data set in a reasonably short time of less than 45 minutes.

An automated procedure to scan the position of the undulator middle plane relative to the electron beam position was implemented. The scan time of one undulator segment during our measurements is four minutes, but it can be significantly reduced by optimizing the communication process between the local PLC and the DOOCS control.

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