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Photon Diagnostic for FLASH2020+: Analysis of Spontaneous Radiation for Undulator Alignment

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Photon Diagnostic for FLASH2020+: Analysis of Spontaneous Radiation for Undulator Alignment

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Abstract. Within the FLASH2020+ program, DESY is aiming to significantly improve the flexibility and availability of its pioneering FEL FLASH for users. Increasing the electron beam energy to 1.35GeV will make wavelengths available up to the oxygen K-edge on the fundamental harmonic. Exchanging the current fixed gap undulators in the FLASH1 branch for variable gap devices will allow for fully independent operation of both branches in the future. The 11 new Apple III type variable polarization undulator segments will have a period length of 33mm and a length of 2.5m each.
This paper presents the development of a photon diagnostic station for FLASH2020+, an additional tool for alignment and commissioning of the undulators. The diagnostic station will be located about 50m downstream from the last undulator. It will allow for the measurement and correction of the electron beam orbit as well as for the measurement of the undulator K-values. In addition, the system can be used to investigate the phasing of the undulators in two adjacent cells by analysing their spontaneous radiation.

1. Introduction

FLASH2020+ [1] FEL line layout consist of 11 variable polarization undulators (APPLE III) of 2.5m length each with intersections of about 0.8m between the undulators. The intersection contains diagnostic instruments and vacuum devices, quadrupole magnets and phase shifter chicane magnets. Additionally, and complementary to the electron beam-based alignment of the undulator section of the machine, also a system for photon beam-based alignment shall be implemented. It will be located downstream of the last undulator segment at a distance of about 50m from the first undulator. The photon diagnostic system is based on the analysis of the spontaneous radiation of the undulators in order to measure the electron beam orbit and the K parameter of the undulator [2,3,4]. The intended photon diagnostic station is composed of a crystal monochromator used to select the photon energy and a synchrotron radiation imager.

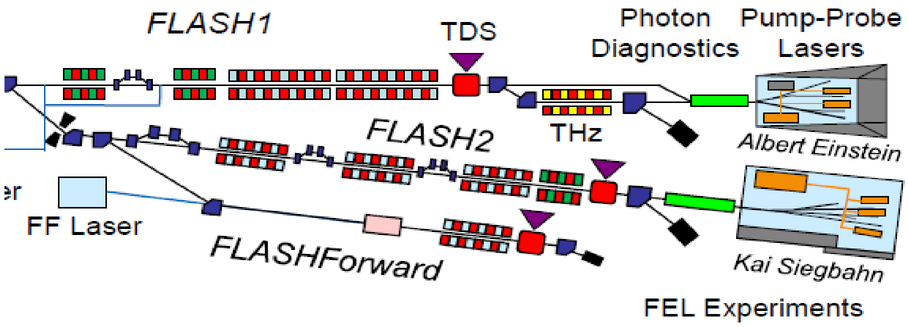

Figure 1. FLASH2020+ FEL Line. The Photon diagnostic station is located at 50m downstream of the first FLASH1 undulator.

2. Specification for the photon diagnostic station

The photon diagnostic spectrometer requires a photon beam with sufficient photon flux in order to image the spontaneous radiation beam profile with good quality, a small photon beam divergence to allow the transport of the entire photon beam in the beam pipe towards the diagnostic station, as well as the spectrum of the photon beam which must be in the working range of the monochromator crystal. The FLASH2020+ parameters relevant for the layout of the spontaneous photon diagnostics are given in table 1. The spectral and spatial photon beam distributions discussed in the following have been simulated using SRW [5]. For the electron beam, a bunch current of $1 \cdot 10^{-10}$A was assumed with an emittance of 0.6nmrad and an energy spread of 0.1MeV. It can be noted, however, that the electron phase space of an FEL like FLASH deteriorates the photon emission characteristics in the VUV-energy range only to a very minor extent.

Table 1. Relevant parameters of the photon diagnostic for spontaneous radiation at FLASH

Source point distance (D)	50	m
Operation energy	750-1350	MeV
Undulator period (λ_u)	33	mm
Undulator length (L_u)	2.5	m
Undulator K value	1-3.7	
Beam pipe diameter	6	mm
Monochromator energy range	~2	keV

For a given beam pipe inner diameter of 6mm, we can compute the photon beam energy that can be transported from the undulator to the photon diagnostic station:

$$\sigma = 2\sigma_\theta \cdot D = 2\sqrt{\frac{\lambda_r}{L_u}} \cdot D$$

where σ is the photon beam size, σ_θ is the photon beam divergence in a Gaussian approximation, and λ_r is the photon wavelength. Assuming that the photon beam size equal to beam pipe diameter, the photon beam that can be transported must have a wavelength of $\lambda_r \leq 9nm$, which corresponds to a photon energy of $E_r \geq 137eV$. We deduce that in order to obtain this given photon wavelength, the undulator K value must be $K \leq 2.5$, assuming using the lower order harmonic (for higher photon flux). Figure 2 shows the simulation of the photon spectral flux in a 6x6mm^2 screen at 50m from the undulator and for K=2.5.

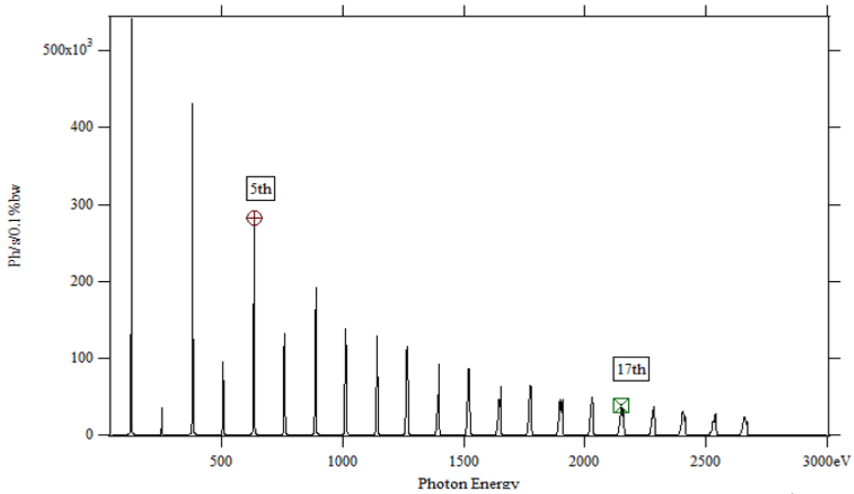

Figure 2. Radiation spectrum at 50m from the undulator on a 6x6mm^2 screen.

The radiation spectrum is composed of odd and even harmonics and the fundamental at 127eV. However, the photon diagnostic must be done at higher harmonic in order to overcome the limitations by the small vacuum chamber aperture and to reach the crystal working range at about 2keV. In this case the first odd harmonic after 2keV is the 17th harmonic and 16th order for the even harmonic. For such higher harmonic, the diagnostic could be challenging as the photon flux becomes lower and the phase error of the undulator (not included in the simulation) impact significantly the high order harmonics. In order to work at lower energy and increase the photon flux, an Indium Antimonide crystal, InSb(111) with an energy range down to 1.75keV can be used as monochromator [6].

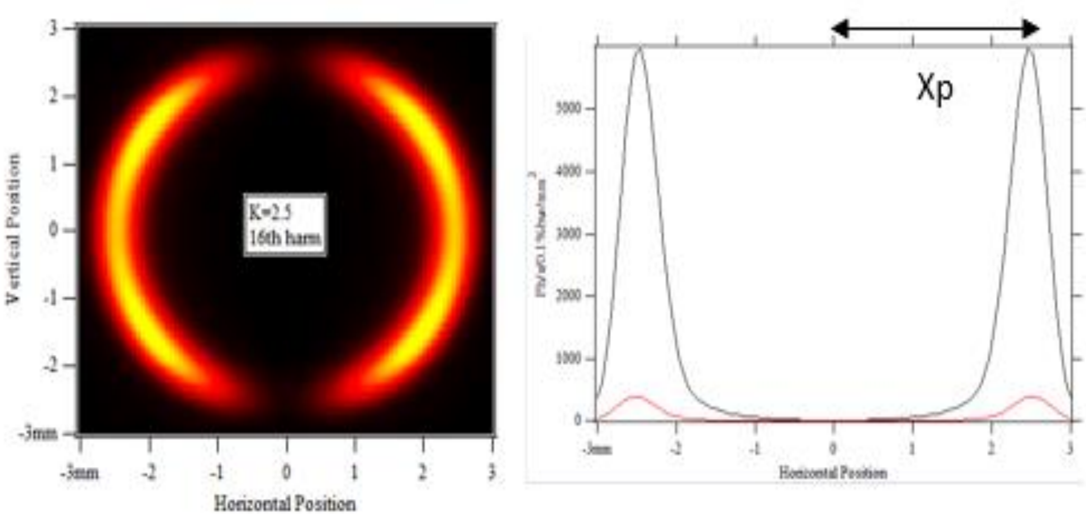

Figure 3. Spatial distribution of the photon beam at 50m for the 16th harmonic (left). Plot of the profile in the vertical mid-plane (right) for K=2.5 (black) and k=1 (red).

The K value can be evaluated from the photon spatial intensity distribution given in figure 3. Using the equation $\lambda r = \frac{\lambda u}{2n\gamma^2}\left(1 + \frac{K^2}{2} + \gamma^2\theta^2\right)$, where n is the harmonic order and θ is the radiation opening angle given by $\theta \cong X_P/D$, the undulator K value can be determined precisely. The sensitivity of this measurement method is shown in figure 4, where the K value is slightly modified by a value of 10^{-3}.

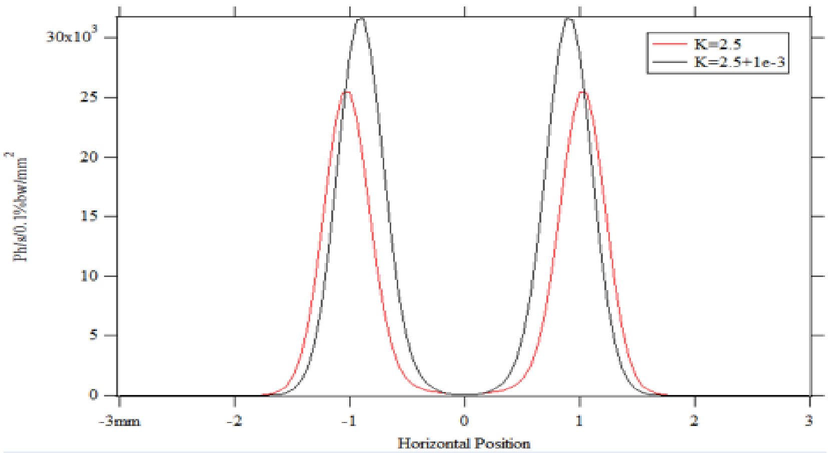

Figure 4. Plot of the photon spatial intensity for K=2.5 for the 14th harmonic (1.78keV) at 25 m (last undulator).

Using InSb(111), the 14th harmonic (1.78keV) can be used to analyze the spontaneous radiation. In this case, the image size at 25m from the last undulator is about 2mm peak-to-peak. The K value deviation of 10^{-3} leads to a peak spatial position shift of 120um, and twice that value for diameter change of the ring-like intensity distribution. This sensitivity will enable a precise tuning of the undulators K value with a precision of 10^{-3}, comparable to the Pierce parameter for the FEL lasing.

3. Conclusion

The development of a photon diagnostic station for commissioning and alignment of the undulator section of the upgraded FLASH 1 FEL is in progress. It is planned to extend the established concept of a so-called K-monochromator together with an imager station for analysis of the spontaneous radiation of the single undulators towards lower photon energies. For the purpose, an InSb(111)-based crystal monochromator with an energy range down to 1.75keV is proposed. The simulations show that the diagnostic can be achieved by utilizing high order harmonic radiation and thus provide the required sensitivity to tune the undulator K value with a precision of 10^{-3}.

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