Commissioning of Multi-Segmented Undulators at the TESLA X-ray FEL

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Abstract

Commissioning of the TESLA X-ray FEL undulator cells will start at low electron energy and long photon wavelength (~6nm) corresponding to the bottom end of TTF phase II operation. Electron and photon diagnostic schemes will be used to monitor the beam trajectory through the various undulator segments. Furthermore, photon diagnostics has to control all undulator gaps and prove the phase tuning of adjacent segments. Using higher harmonics of the spontaneous radiation of individual undulator segments, the photon diagnostic station can cover a wide spectral range and will be able to cope with the progression towards lower SASE wavelength (~1Å). The use of variable gap undulators allows to realize the photon diagnostic section in a single device located in the photon beamline downstream of the last undulator cell.

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1. Introduction

X-ray FELs require very long undulators in order to achieve saturation at wavelength in the 1Å-range. The TESLA XFEL undulators will be made of up to ~50 short cells of 6.1 m length [1], i.e. a 5 m long undulator segment and a 1.1 m long intersection module containing items such as phase shifter, quadrupole, BPMs, and steering coils. The proposed X-ray diagnostics [2] is a tool for alignment and commissioning of the numerous undulator cells along an XFEL beamline. Photon diagnostics is also used successfully or foreseen in other SASE FELs as TTF [3,4], LEUTL [5] or LCLS [6].

In the commissioning phase of the TESLA XFEL operation will start at the TTF phase II lower limit (~6nm) and continuously progress towards shorter wavelengths. Here, diagnostic issues are discussed for undulator SASE3 (λ_U=45mm) which provides a 1[st] harmonic at 6.4 nm (193.5eV) for an electron energy of 2.5 GeV. The ρ-parameter corresponding to this wavelength is $\rho \sim 1 \cdot 10^{-3}$ which leads to considerably lower alignment requirements in the undulator section, namely a trajectory displacement within Δx=13µm, trajectory tilt $\Delta x'$=2.6µrad, gap adjustment Δg=6.5µm, and a phase tuning of a few degree.

The diagnostic station with a monochromator as a principal instrument is located about 100m downstream from the last undulator cell. The spatial distribution of the spontaneous radiation of individual or several consecutive undulator segments is imaged and analyzed in order to optimize angle and position of the electron beam trajectory, to verify the magnetic gap and to adjust the phase match between two undulator segments [7].

Wavefront calculations have been performed for the commissioning parameters of SASE3 in order to assess the feasibility of the proposed concept.

2. Trajectory alignment

The 1[st] harmonic at 193.5eV is not suited to monitor the electron trajectory in the undulator

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because its spatial distribution with a FWHM of 6.5mm is too broad. Observing the 5th harmonic results in a sufficiently narrow beam pattern which can resolve a trajectory misalignment in the range from 2.8µrad (observation precisely at 5th harm.) to about 1.8µrad for a detuning of the observation energy to slightly higher values (Fig.1). This will satisfy the required accuracy. The expected intensities are in the order of 10^5 and about twice as high as for the 1st harm.

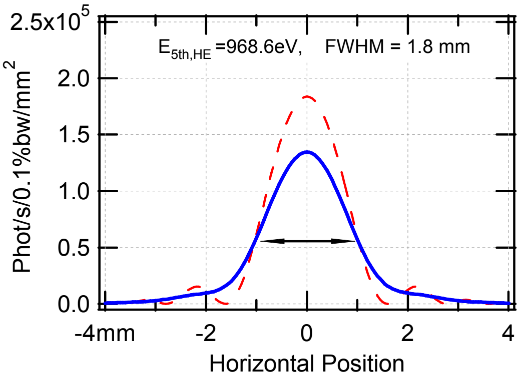

Fig. 1. Spatial distribution of the 5th harmonic (detuned to higher energies). Solid: incl. emittance effects; dashed: single electron

3. Gap adjustment

Measuring the beam intensity at fixed monochromator energy (5th harm.) as a function of the undulator gap will result in a sharp peak corresponding to related nominal gap. Assuming an intensity determination with only 20% accuracy results in a resolution of Δgap=3µm. A gap deviation of 6.5µm causes an intensity drop by a factor 2.4 .

4. Phase tuning

The phase of two successive undulator segments can be tuned by maximizing the intensity at either the 1st or 5th harmonic (fixed observation energy) as function of the electron beam delay (Fig.2). Though both ways allow to set the phase with an accuracy of several degrees, working at the 5th harm. gives higher contrast (~280), higher overall intensity (10^6) and higher sensitivity.

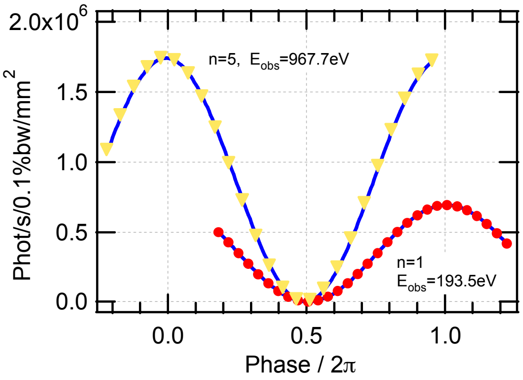

Fig. 2. Intensity variation at constant observation energy as function of the phase relation between two adjacent undulator segments.

5. Observation of high harmonics

A diagnostic station for the commissioning phase at 6.4nm requires a completely different hardware than the one for the final 1Å XFEL operation. The useful energy spectrum of SASE3 (spontaneous) at the initial settings ranges above 10keV. It could be attractive to work with this diagnostic scheme at E~6keV in order to use the same hardware setup as it will be needed at final stage and to accommodate smoothly to the progression towards shorter SASE wavelengths.

As known field errors and in particular the phase error degrade the performance of especially the high harmonics. Calculations for a non-ideal magnetic field with 0.5% rms Gaussian noise producing a 3° rms phase error result in a still symmetric spatial distribution at 6keV with FWHM=1.5mm which would be suited for trajectory and gap optimization. However, the actual applicability of high harmonics strongly depends on the attainable phase error.

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