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Preliminary Measurements of the High-Gain FEL Radiation Properties Along the Radiator

T. Shaftan, H. Loos, B. Sheehy, L.H. Yu

NSLS, Brookhaven National Lab, Upton, New York

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PRELIMINARY MEASUREMENTS OF THE HIGH-GAIN FEL RADIATION PROPERTIES ALONG THE RADIATOR

T. Shaftan*, H. Loos, B. Sheehy, L.H. Yu, NSLS, BNL, Upton, NY 11973, USA

Abstract

We present preliminary experimental results on evolution of properties of the DUV FEL [1,2] radiation along the radiator. Intercepting the electron beam at the different locations inside the undulator we recorded and analyzed transverse profiles, spectra and intensity of the FEL output. Shot-to-shot fluctuations of the FEL radiation may significantly affect the accuracy of measurement. In the paper we present and discuss a single-shot measurement technique, based on a special imaging system.

INTRODUCTION

Significant progress in understanding of high-gain FEL physics has been achieved during past decades. Both analytic and simulation tools are developed and being used at the design of Self-Amplified Spontaneous Emission (SASE) [3,4] or High Gain Harmonic Generation (HGHG) [5,6] Free Electron Lasers. Start-to-end simulations [7,8] model the entire beam line from the generation of the photoelectrons at the gun to the transport of the FEL radiation light to the user station. Because the beam dynamics changes significantly along the beam line a series of "expert" codes are used. There are few of FEL simulation programs that calculate an FEL output for given initial shape and distribution of the electron bunch [9,10].

The code accuracy of prediction the FEL performance is being verified experimentally. FEL radiation transverse profile, spectrum, energy per pulse, etc. are important test points for any FEL code. Usually, all of the radiation parameters are measured and being compared with an FEL simulation at the end of the undulator. However, one of the key FEL parameters, gain length, is being measured by detecting the radiation intensity at the discrete points along the undulator.

There are several approaches for the gain length measurement. One of them [11] relies on the special optical system, transporting the FEL light from different cross-sections of the undulator to a single detector. Another approach [12] utilizes few detectors located along the undulator. In both cases, inserting a mirror deflects radiation to the detector and allows for measurements of the radiation intensity at the mirror location. Third approach is based on deflecting the electron beam by the trajectory corrector [13]. In this case the only portion of the undulator before the corrector contributes to the radiation intensity measured at the detector downstream of the undulator.

These measurements provide with a single parameter, that is, with radiation intensity distribution along the radiator. However, many more radiation parameters can be obtained using similar experimental set-up. Measuring transverse radiation distribution and spectrum along the radiator would present important data to be compared with a simulation. This is particularly valuable when electron beam enters the saturation regime.

Spectral measurements of the SASE radiation evolution have been performed at LEUTL FEL (APS) [14,15]. During this experiment SASE radiation spectra were recorded at the different locations along the radiator. The analysis for the first and second harmonics has shown quantitative agreement with predictions of a simulation code.

Another application of such a "complete" characterization of the radiation properties along the radiator is in optimization of the FEL performance. Measured data may be directly compared with the electron beam parameters, such as emittance, trajectory or beam size. Necessary optimization of the electron beam parameters follows as a feedback.

In this paper we present initial results of the characterization of HGHG radiation evolution along the radiator.

The radiation spectrum, especially in SASE case is subject of fluctuation. Random set of SASE spikes from shot to shot makes comparison with simulation to be a difficult task. If measurement takes significant time, the beam parameters (for both SASE and HGHG) may drift resulting in incomprehensive set of data. In the closing we discuss a single-shot version of the spectral measurements device.

EXPERIMENT

The experiment has been performed at the DUV FEL at BNL [1,2]. The 800 nm laser radiation is used as a seed for HGHG FEL. The radiator is tuned to the third harmonic of the seed radiation (266 nm). In the experiment we measured properties of the output at 266 nm.

The experimental set-up is shown in Fig. 1. The 10 meter long NISUS undulator serves as a radiator in HGHG FEL magnetic system. The undulator is equipped with variety of diagnostics and correction, including 16 four-wire correctors equally distributed along the whole length. The diagnostics system at the experimental area consists of photodiode, CCD camera and spectrometer.

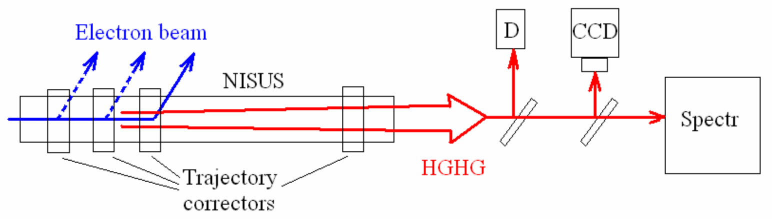

Fig. 1: Experimental set-up.

Using four-wire correctors we deflect the electron beam at consecutive locations along the undulator axis. We have chosen the kick strength to be sufficient for steering the beam onto the vacuum chamber wall at approximately 50 cm downstream of the corrector. Thus the only radiation from the portion of NISUS preceded the corrector has been recorded.

The radiation intensity as a function of the distance along the undulator (gain curve) is plotted in Fig. 2. The measured HGHG power at the end of NISUS was measured as 25 μJ.

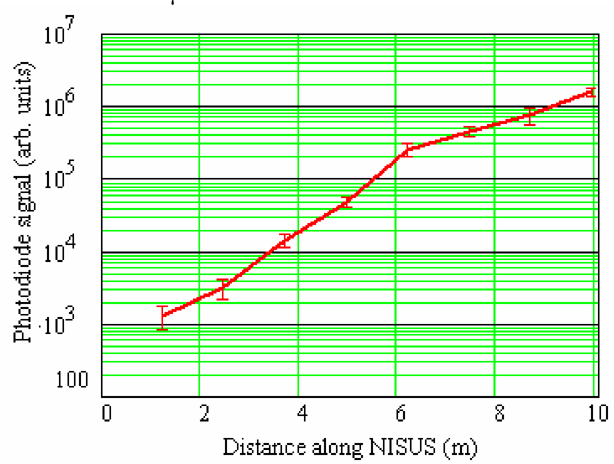

Fig. 2: HGHG gain curve.

Fig. 3 shows the images of the HGHG radiation observed at different locations along NISUS.

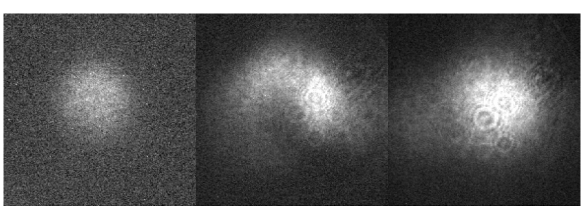

Fig. 3: Transverse images of HGHG radiation corresponding to beginning, middle and end of NISUS.

Dependence of the recorded transverse spot size on the distance along NISUS is plotted in Fig. 3.

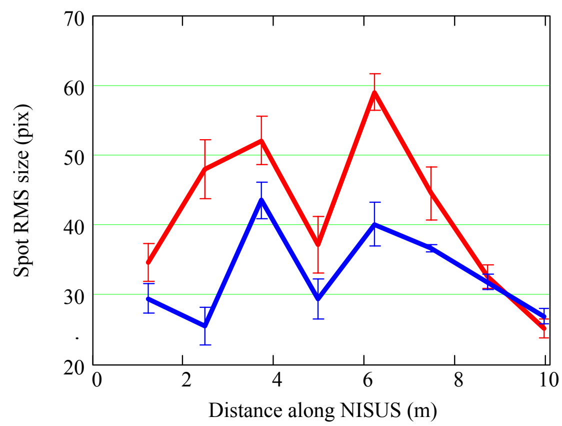

Fig. 4: Dependences of the HGHG spot size.

The next plot (Fig. 5) presents evolution of the spot center versus distance along NISUS. This dependence will be compared with electron beam trajectories in the radiator.

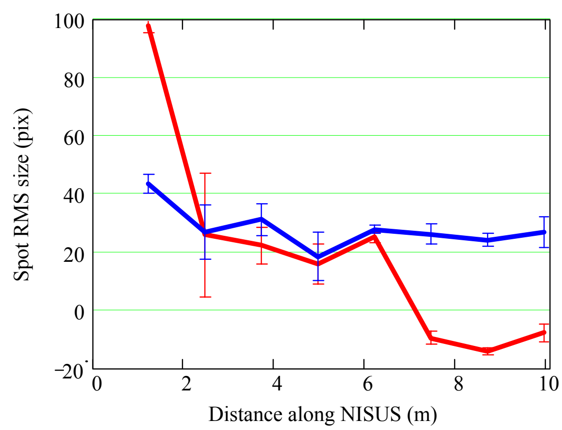

Fig. 5: Dependences of the center position of the HGHG spot.

Next we discuss the spectral measurements. The HGHG spectra are plotted in the next figure (Fig. 6). The black line corresponds to the central wavelength of the HGHG spectra. Average single-shot spectrum width is shown as blue error bars in red, averaged multi-shot width is plotted as blue error bars. From the figure we can observe that the central wavelength shifts by approximately 0.15 nm at the end of NISUS. Assuming these losses due to the radiated power we can estimate the peak power in the HGHG pulse. It can be shown that the peak power in MW is given by the following expression:

$$P_p = \frac{mc^2}{2e}\gamma I_p \frac{\Delta\lambda}{\lambda} = 0.256 \cdot \gamma I_p [A] \frac{\Delta\lambda}{\lambda}$$

Substituting experimental parameters in this expression (γ=350, λ=266 nm, $\Delta\lambda$=0.15 nm, I_p=400 A) we get about 20 MW. Assuming HGHG pulse length of 1 ps we calculate 20 μJ for the pulse energy, which is very close to the measured value.

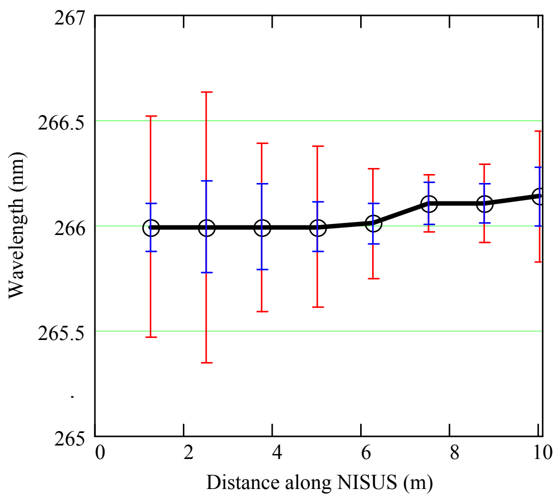

Fig. 6: Evolution of the HGHG spectrum.

On the next figure (Fig. 7) we present RMS fluctuation of the HGHG single-shot spectrum width along NISUS.

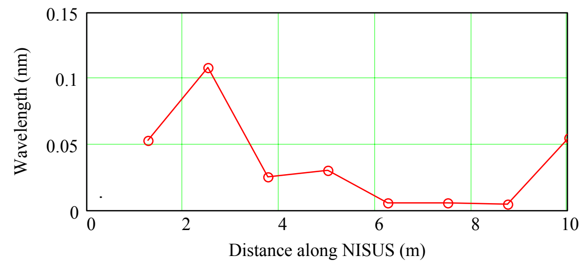

Fig.7: RMS fluctuation of the HGHG single-shot spectrum width.

SINGLE-SHOT METHOD OF SPECTRAL MEASUREMENTS

As we discussed in the Introduction, shot-to-shot fluctuation of radiation, as well as, accelerator performance stand technical problems for the accurate measurements of the radiation properties. In Fig. 8 we present a proposal for a single-shot spectral measurement device.

Special optical system (sketched as a green lens in Fig. 8) focuses the radiation downstream of the radiator. Due to the depth of image, the radiation from the beginning of undulator is focused later after the lens, vice versa for the end of the undulator. Using auxiliary optics (not shown in Fig. 8) and beam splitters one can split portions of radiations corresponding different parts of the radiator. Then these portions are recombined on the spectrometer slit.

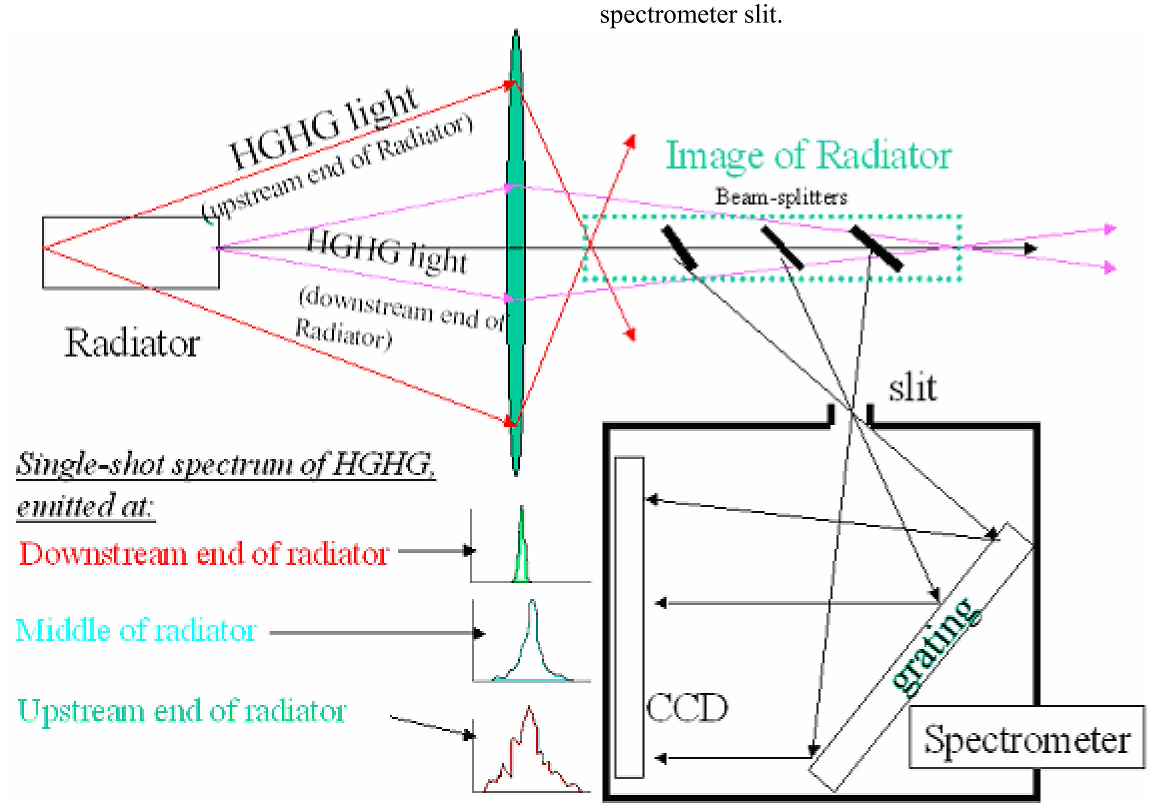

Fig. 8: Schematics of a single-shot measurements set-up.

Using non-dispersive axis of spectrometer we misalign different rays in order to see spectral patterns recorded at the different locations on the spectrometer CCD. Thus, spectra of radiation from different locations along the radiator can be observed.

We note that the only diverging part of emitted radiation can be used in this set-up. The optical system must block the radiation coming at small angles as it is generated along the whole radiator. Another issue is the large range of the radiation intensity from different parts of the radiator (6-7 orders of magnitude). This problem can be somewhat relieved by choosing an appropriate transmission of the beam splitters. However in experiment only last portion of the radiator might be effectively measured. Also, another problem is in the optical guiding effect [16] that will occur at the saturation. This will modify the angular divergence of the radiation, which has to be taken into account.

The study and optimization of the optical system for DUV FEL is in progress. Preliminary design is based on two-lens system with central and iris apertures.

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