A Diagnostic System to Measure SASE-FEL Radiation Properties along the 4-meter VISA Undulator

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1. Introduction

During the last several years there has been a great experimental effort in the developing high gain SASE free electron lasers. Single pass FEL gain of 10^5 was achieved in the far infrared [1]. The research is directed towards smaller wavelengths and yet higher gain, with the ultimate goal of constructing the x-ray FEL [2]. A number of experiments are under the development to demonstrate SASE at visible and UV range. However, many important properties of the process of self-amplified spontaneous emission are still to be verified experimentally. As a part of the VISA experimental program (visible-to-infrared SASE amplifier [3,4]), we have constructed a diagnostics system, which will allow a detailed characterisation of the FEL process along the 4 meters of VISA undulator.

2. VISA parameters

The experiment will utilise the electron beam of the BNL Accelerator Test Facility [5]. Its high brightness photoinjector can produce a peak current of 200 Amp with the normalised emittance of 2 π-mm-mrad. According to simulations [6], these beam properties are sufficient to saturate SASE-FEL in less than 4 meters in the VISA undulator.

The undulator was built at SLAC and measured at BNL [7]. It has a period of 1.8 cm with the on-axis peak field of 0.75 T. Quadrupole magnets were added to the Halbach array, to provide a strong focusing in the both planes.

The first round of the experiment will use an electron beam of 71 MeV, to generate the fundamental FEL harmonic at 0.8 μm wavelength.

3. Measurements

The photon beam itself is the best diagnostic for the FEL-process. The intra-undulator probes will be used to extract the photon beam at eight different locations along the undulator. Utilising the relay imaging system, the light from all ports will be transported into the diagnostics area. It is equipped with instruments that allow measuring the radiation intensity, spectrum and angular fluence of the FEL light.

On-axis power growth along the undulator will be an accurate measurement of the FEL gain length, and generally demonstrate the dynamics of start-up from noise. It is expected, that the exponentially growing term [8] will become dominant within the first two gain lengths. Simulations suggest (fig. 1) the field gain length of L_G=38 cm, and that saturation will occur just before the end of the undulator.

The angular profile of the radiated beam can be directly linked to the transverse coherence of the beam microbunching. At the beginning of the

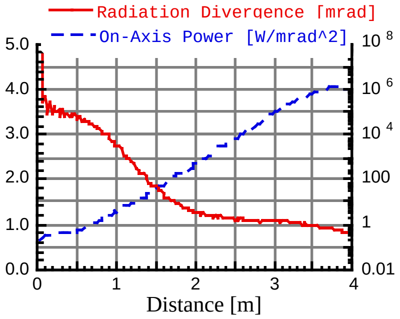

Figure 1: On-axis power and angular divergence of the radiated light simulated with GENESIS code.

undulator, the SASE-FEL process is degenerate by definition, and the higher order modes produce a beam with large divergence (fig. 1). Further along, since VISA FEL is a strongly diffracting system ($\tilde{a} < 1$), a single mode dominates [9] and the full transverse coherency is achieved long before the saturation. Theory predicts the fundamental mode to have 1/e angle of 1.4 mrad [10].

A slippage length (the phase advance of the radiated light with respect to the electron beam in the undulator) of $\sigma_c \approx 0.2\ \mathrm{mm}$ is anticipated in the VISA experiment, which is shorter than the electron beam bunch length of 1.4 mm. The coherence of the light source is localised within roughly half of the slippage length; hence, the radiation is emitted in the form of coherent spikes. Indirect indications of the spike formation can be deduced from measuring FEL radiation spectrum and shot-to-shot power fluctuations [11]. In the future we plan to use a single-shot autocorrelator constructed at LLNL, to measure the spikes explicitly. One application to these studies could be a proposed scheme [12] to chirp an electron beam and use a grating compressor in order to increase the peak power of LCLS.

4. Instrumentation

There are two important aspects in the instrumentation design: the vacuum probe configuration and the optical transport. The vacuum probes not only extract the FEL light out, but also serve as beam position monitors.

A copper mirror with two reflecting surfaces is placed into the beam-line by the probe (fig. 2). In the inner position it reflects the beam image produced by the YAG crystal. A periscope design assures absolute measurements of a beam position along the undulator length, which are of critical importance for maintaining the required trajectory straightness of 40μm per gain length [6]. Shifting the probe outward moves the second reflecting surface of the mirror into the beam path, to direct the FEL light through the view port into the optical transport line.

The transport line serves to deliver the photon beams, originating at the different locations along the undulator, into the diagnostics area about 20 meters away. It is designed to preserve the beam properties and allow multiplexing between the ports. For this purpose a periodic lens array is used, with the period of 50 cm, the same as the probe spacing. Thus, the photon beam from any diagnostic port will travel through the even number of lenses transforming into self (assuming the azimuthal symmetry). Optical flippers serve to inject the beam from a selected port into the transport line. This set-up enables identical treatment for the light from all eight ports for the reminder of the transport line [4], and in the diagnostics room. The diagnostics area is equipped with a Joule meter, CCD camera, and spectrometer for measurements of radiation properties.

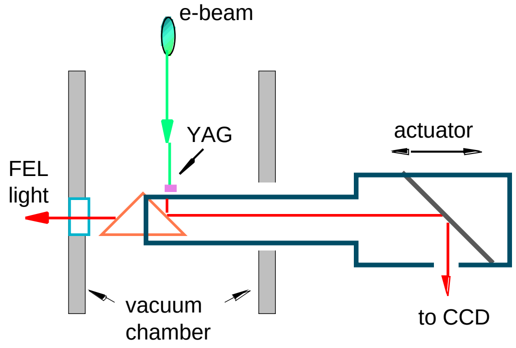

Figure 2: Intra-undulator probe schematics.

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