DIAGNOSTICS SYSTEM FOR THE NISUS WIGGLER AND FEL OBSERVATIONS AT THE BNL SOURCE DEVELOPMENT LAB

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Abstract

The Deep Ultra Violet Free Electron Laser (DUV-FEL) experiment is being commissioned in the Source Development Laboratory (SDL) at NSLS. It utilizes the 10 m long, 3.9 cm period NISUS wiggler. The initial FEL commissioning is at 400 nm wavelength and at 140 MeV electron beam energy. The electron and photon diagnostics and alignment systems are described. These systems include Cerium doped YAG crystals, Optical Transition Radiation (OTR) monitors, and photodiodes along the wiggler, as well as light and electron spectrometers at the end of the beamline. Measurement of FEL output power and spectrum are presented, as commissioning progresses.

1 THE DESCRIPTION OF DIAGNOSTIC SYSTEM IN THE NISUS WIGGLER

The Deep Ultra Violet Free Electron Laser (DUV-FEL) experiment is being commissioned in the Source Development Laboratory at the National Synchrotron Light Source (NSLS), Brookhaven National Laboratory (BNL). The goal of the project is to produce radiation at a wavelength less than 100 nm, utilizing the High Gain Harmonic Generation (HGHG) method, which was demonstrated in a proof of principle experiment at ATF BNL [1-4]. In the first stage of the project, the system is being operated in Self-Amplified Spontaneous-Emission (SASE) mode, in order to understand the performance of the system. A 10 m long, 3.9 cm period hybrid wiggler (NISUS) is used with a peak field of 0.31 Tesla and 20.6 mm gap; 140 MeV electrons are passed through the wiggler producing radiation at 400 nm wavelength.

The wiggler consists of 16 sections; each section is 62.5 cm long with 16 periods. Each section has 6 alternately canted pole tips (10.8 mrad) to provide a horizontal focusing in the wiggler. A Four-wire system in each section provides variable focusing, which is necessary to get equal focusing in both transverse directions. The four-wires can also excite dipole fields to correct trajectory errors. In addition, at the top and bottom of every section, pancake shaped dipole magnets can provide uniform vertical dipole fields, to correct horizontal trajectory.

Pop-in monitors between sections are used for electron and laser beam diagnostics. The top view of the pop-in system is shown in Figure 1. There are total of 17 monitors including the ones in front and at the end of the wiggler. The pop-in monitors have two different purposes, which are used by inserting them to two different positions. All pop-ins have a Cerium doped YAG crystals to image the electron beam. In the first case, the electron beam is blocked by the YAG crystal and the green light emitted by the crystal is transported outside of the vacuum chamber by a periscope to the south side of the wiggler. In the second case, the pop-in will be inserted less so that a 45° mirror reflects OTR and FEL light to the north side of the wiggler.

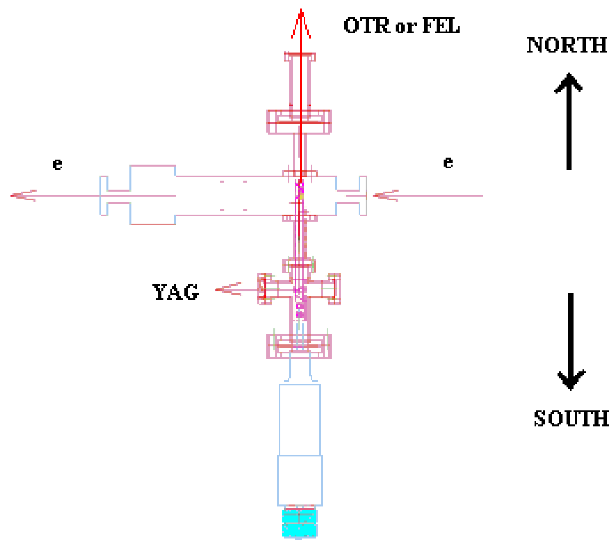

Figure 1: NISUS pop-in layout

For the electron beam profile measurement, the YAG crystal is moved into the beam line and the image is relayed to a CCD camera. The crystal is held by a 4 mm diameter fiducial, which also serves as imaging and calibration tool.

On the north side, since the energy of the FEL light washes out that of the OTR we use a 0.05 mm thick titanium foil in front of the mirror to block the FEL light. There are four OTR stations along the NISUS wiggler. Other pop-ins, without foils, are used for the FEL energy measurements. A photodiode detector [5] is used to measure the energy of the radiation. Also a band pass filter centered at 400 nm with 1.5 nm bandwidth is placed in front of the detector to select the right wavelength. Currently 7 energy detectors are installed along the wiggler.

2 ALIGNMENT PROCEDURE

A fiber coupled green Helium-Neon laser is utilized for alignment of the electron beam in the wiggler. A single mode fiber is coupled to the He-Ne laser to reduce the pointing instability due to laser temperature fluctuations. The laser is aligned through the irises before and after the wiggler. An automated computer controlled program inserts the pop-ins one by one and records the positions of the laser beam at each pop-in. Then these positions are used as reference for the electron beam trajectory measurements in the wiggler. The reproducibility of the pop-ins is about 5-10 µm and the resolution is about 10-15 µm.

3 ELECTRON BEAM TUNING

The electron beam is produced by UV light from a solid-state laser (Titanium: Sapphire with conventional harmonic generation) illuminating the cathode of an RF photo-injector. This intense electron bunch is then accelerated by an electron linac [6]. Two SLAC type linac tanks accelerate the electrons to about 70 MeV with the second tank dephased by about 24-28 degrees. Then a four-magnet chicane is used to compress the electron bunch [7]. The typical rms bunch length of the uncompressed beam is 2-3 ps, and after compression it becomes 0.2-0.5 ps with a peak current of several hundred Amps. The third linac tank accelerates the electrons slightly off crest to remove the remaining chirp from the compression and the fourth one accelerates up to the initial commissioning energy of 140 MeV.

The electron bunch length is measured at the end of the accelerator using the zero phasing method [8] with the fourth linac tank. Without initial energy chirp on the beam one obtains the same bunch length from both positive and negative slope zero phase angles. However, if there is an initial chirp on the beam, one gets different bunch lengths from both zero phase angles. Here one should be careful determining the actual bunch length. If the initial chirp were less than the chirp introduced by the accelerator, then the actual bunch length would be the average of the two measurements [8]. Thus $z_{rms}=(z^{+}+z^{-})/2$ where z^{+} and z^{-} are the bunch lengths measured at positive and negative slope zero phases. If the initial chirp is more than the chirp introduced by the accelerator, then the actual bunch length would be $z_{rms}=|(z^{+}-z^{-})|/2$. In most cases initial chirp is small so that the first case applies. However for strong compressions it may be difficult to completely remove the chirp with the third linac tank. We observed some cases where we had to apply the second condition.

The electron beam parameters such as emittance and twiss parameters are measured downstream of the linac using the quadrupole scan method. The electron beam is matched to the wiggler using a MAD (electron tracing program) or a Matlab routine developed at SDL. The matching and trajectory correction can automatically be done by Matlab routines. These emittance measurements are confirmed by a multi screen method using the pop-in monitors along the NISUS wiggler. A more detailed description of this method can be found in ref [9].

4 RECENT FEL RESULTS

4.1 Power Measurement

Recently, SDL achieved FEL gain at 400 nm wavelength. We see a clear exponential increase in the intensity of the SASE light along the wiggler. We don't expect to reach saturation with SASE, but we will saturate using HGHG in the next stage of the experiment. We use SASE to diagnose the wiggler performance.

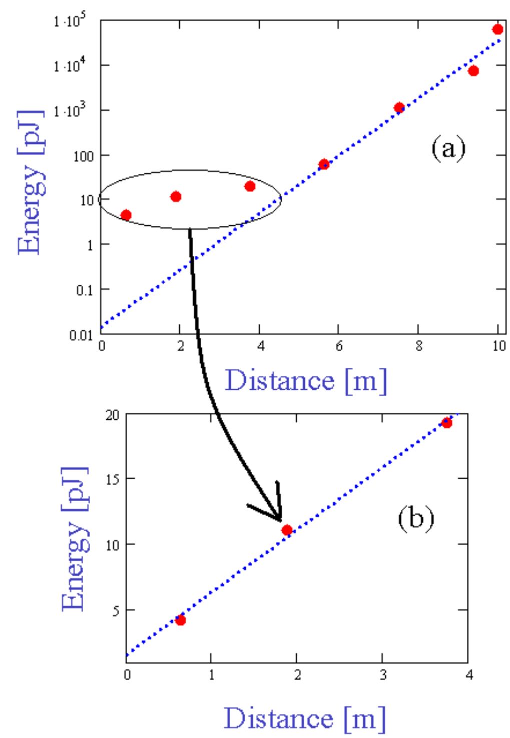

Figure 2: (a) SASE energy as a function of distance along the wiggler in logarithmic scale, (b) the start up energy in circled area is plotted in linear scale.

Figure 2 shows the measurement of SASE along the wiggler. At the beginning the emission is approximately constant with distance, therefore its accumulated energy is linear with distance (Fig 2-b), whereas after several meters, it increases exponentially (Fig 2-a). This measurement yields a power gain length (L_g) of 0.68 m. The data is taken with an emittance of 6 mm-mrad, a peak current of 550 Amps, a total charge of 300 pC and a betatron wavelength of 20 m. Usually SASE saturates at about $20L_g$ which is larger than the present NISUS length of $\sim 15L_g$. The performance of the NISUS wiggler is as expected from design.

4.2 *Spectrum Measurement*

Downstream of the wiggler, the electron beam is bent and separated from the FEL light. The spectrum of SASE is measured by a commercial optical spectrometer [10]. At this wavelength, the light can be detected by a CCD camera at the exit port of the spectrometer. The horizontal axis corresponds to wavelength. We start with uncompressed beam for which only spontaneous emission is produced with wide bandwidth. Bandwidth gets smaller as the aperture gets smaller in front of the detector. After compression the bandwidth significantly narrows down even for a large aperture, which is a clean indication of SASE domination (Fig 3) [11].

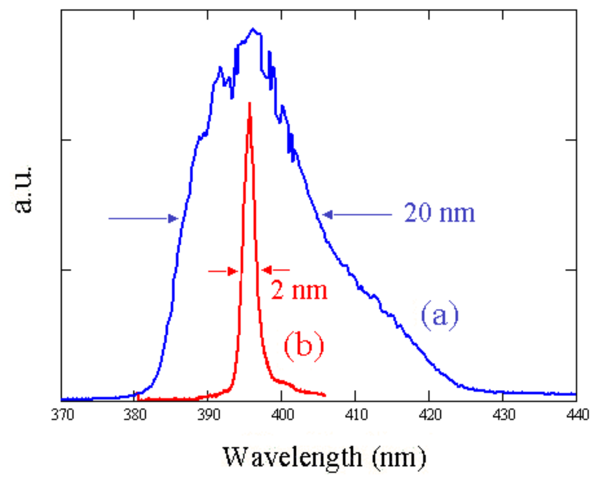

Figure 3: Large aperture spectra of (a) spontaneous radiation, (b) SASE

The single shot spectrum of SASE (Fig 4) was also measured. The separation between the spikes gives information about the radiation pulse length according to the formula $T_b \cong \lambda^2/(0.64c\Delta\lambda)$ [12], which yields about 0.4 ps FWHM.

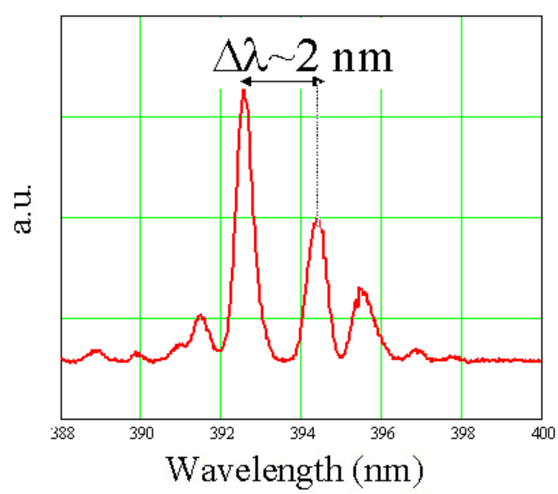

Figure 4: Single shot spectrum of SASE

The energy in the output pulse fluctuates by about 70%, which is expected due to the start up process from shot noise. The power fluctuation of the SASE gives the number of spikes (M) in the spectrum according to the formula $M=1/\sigma^2$ where σ is rms relative power fluctuation [13,14]. We calculate M as about 2, which is consistent with what we see on Fig 4. Radiation pulse length can also be calculated from the coherence length according to the formula $T_b=ML_c/c$ [13,14]. There are several approaches to calculate the coherence length. The first approach uses a step function model [13] using the formula $L_c=N_w\lambda(2\pi L_g/3L_w)^{1/2}$ where N_w is the number of periods and L_w is the length of the wiggler. This yields 0.26 ps FWHM. The second approach uses a Gaussian profile model [14] using the formula $L_c=2\lambda L_g/\lambda_w$ where λ_w is the wiggler period. This yields an rms pulse length of 0.1 ps, which is approximately 0.23 ps FWHM. All these result are in close agreement suggesting the pulse length is around 0.2-0.4 ps. The measured electron bunch length is 0.5 ps indicating that a considerable part of the electron beam is contributing to the SASE production.

5 CONCLUSION

We have described the diagnostic system of the NISUS wiggler and measurement techniques of the various parameters of the electron and FEL beam. The results indicate that the performance of the system is sufficient to proceed to the study HGHG.

6 ACKNOWLEDGEMENT

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