RECENT LCLS PERFORMANCE FROM 250 TO 500 eV*

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Abstract

The Linac Coherent Light Source is an x-ray free-electron laser at the SLAC National Accelerator Laboratory. It produces coherent soft and hard x-rays with peak brightness nearly ten orders of magnitude beyond conventional synchrotron sources and a range of pulse durations from 500 to <10 fs. The facility has been operating at x-ray energy from 500 to 10,000 eV. Users have expressed great interest in doing experiments with x-rays near the carbon absorption edge at 284 eV. We describe the operation and performance of the LCLS in the newly established regime between 250 and 500 eV.

INTRODUCTION

In previous work [1] we have described the first lasing of the LCLS x-ray FEL. Recent improvements include femtosecond electron and x-ray beams [2], harmonic lasing [3] and two color lasing [4]. Soft x-ray Self Seeding is scheduled to be commissioned in the fall of 2013 [5]. The layout of LCLS is shown in Fig. 1. This paper reports on initial LCLS FEL performance between 250 and 500eV. For the initial setup, we established 2mJ FEL energy at 500eV. The machine was then ramped down to 300eV and optimized at this energy. In addition to the beam diagnostics in the Front End Enclosure, the x-ray diagnostic chamber (see Fig. 2) located down beam from the undulator was used to measure the x-ray beam profile and to test the survivability of bulk boron carbide (B4C) material used in x-ray stoppers.

FIRST RESULTS

FEL optimization starts with establishing electron beam projected emittance at the injector less than 0.4um in x and y at 150pC bunch charge as shown in Figure 3. This is accomplished by steering the injector laser on the iris before the gun cathode to achieve a nearly Gaussian laser profile then optimizing the gun solenoid. After loading the design optics, dispersion is corrected after each bunch compressor and dogleg 2. Next the emittance is measured and beta functions are matched after each bunch compressor and dogleg 2

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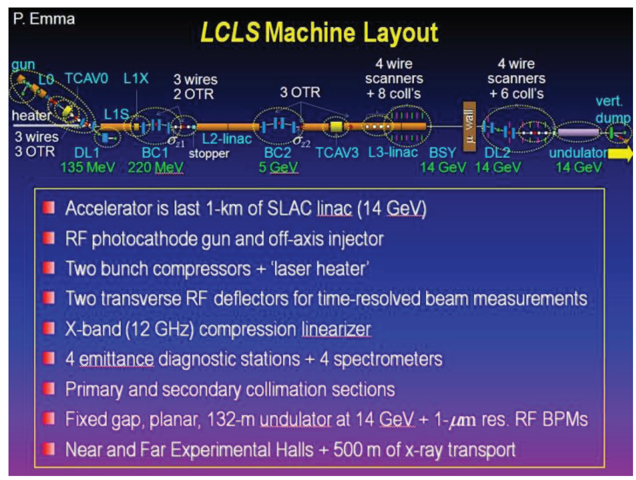

Figure 1: The LCLS machine layout.

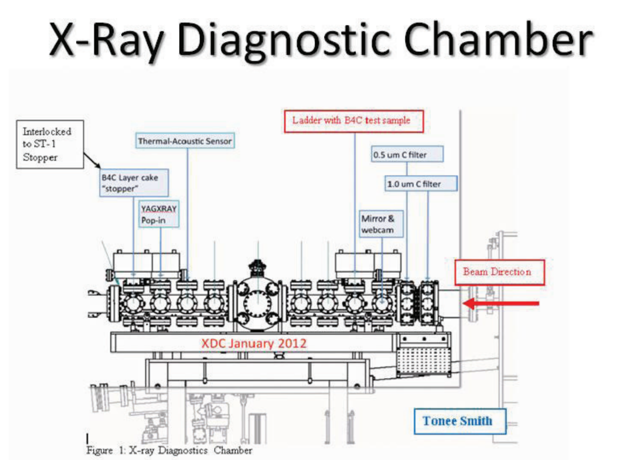

Figure 2: The x-ray Diagnostic Chamber located just down beam of the undulator.

Then the electron beam bunch length, current, beta matching quadrupoles, hard x-ray self seeding chicane delay, laser heater power and undulator taper are optimized to maximize FEL intensity. Figure 4 shows a measurement of the FEL energy after tuning produced 1.3 mJ at 300 eV.

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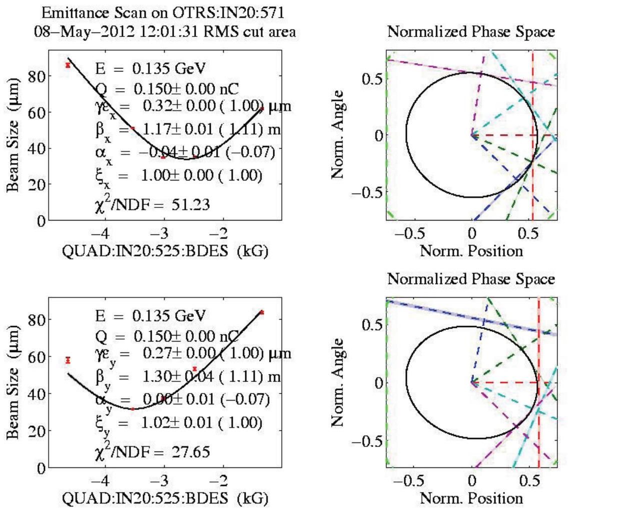

Figure 3: Measured electron beam emittance at the injector showing 0.32 um and 0.27 um in x and y respectively.

The measured x-ray beam profile on a YAG screen located in the x-ray diagnostic chamber is shown in Figure 5. The measured beam size at this location is consistently larger than the size predicted by theory shown in Figure 6. Note that Figure 5 is rms size and Figure 6 is predicted FWHM.

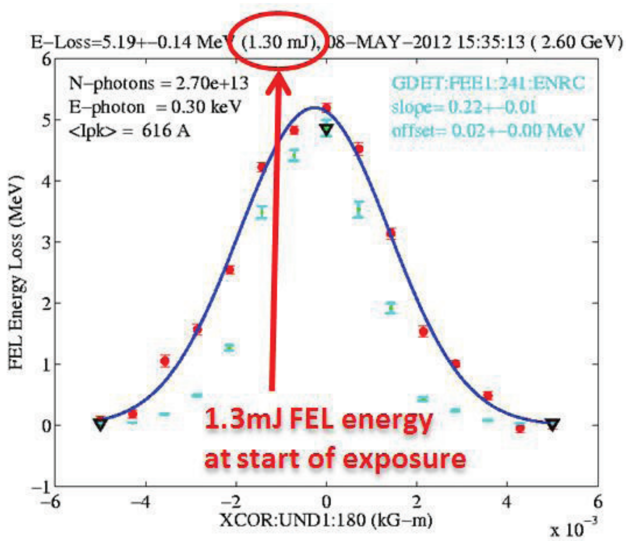

Figure 4: 1.3 mJ FEL energy at 300 eV during B4C exposure.

An integral part of the effort to establish longer wavelength x-rays is a program to verify the survivability of the B4C material used in x-ray stoppers. A new B4C test is performed and survivability evaluated each time the LCLS has a significant increase in FEL energy or repetition rate. Figure 7 shows the calculated B4C dose at the x-ray diagnostic chamber (a.k.a. ST0) location.

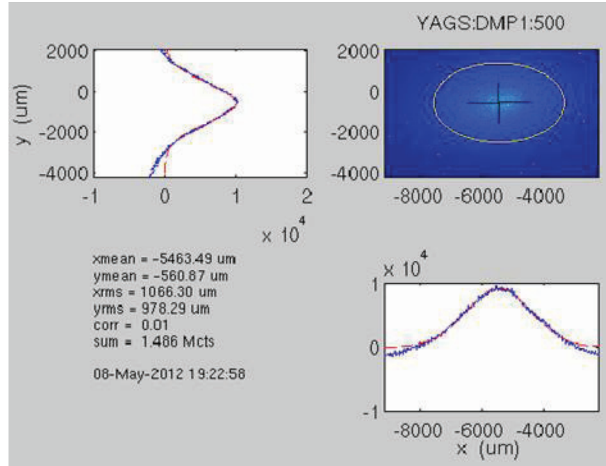

Figure 5: Measured beam profile in both planes at the x-ray diagnostics chamber showing 1066 μm and 978 μm rms sizes in x and y, respectively.

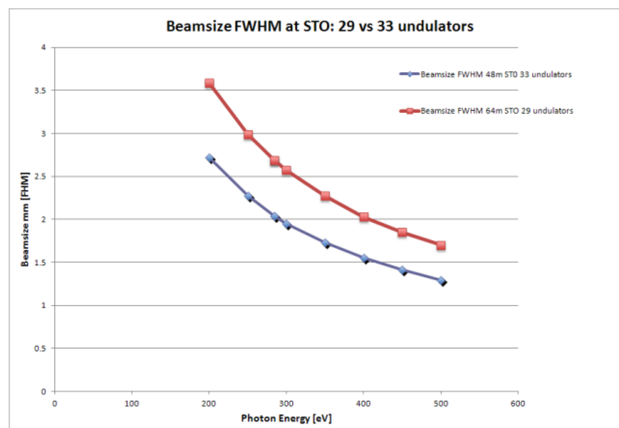

Figure 6: Beam size calculations for the STO location for 33 undulators inserted (blue curve) and with 29 undulators inserted (red curve).

The solid blue curve shows the dose at 1mJ FEL energy and the dashed line shows the dose at 2mJ. Figure 8 shows a scan of the x-ray wavelength vs. FEL energy with a 5 micron carbon filter inserted in the beam. The carbon absorption edge at 284eV is easily confirmed.

Figure 9 shows that the B4C sample appears to be undamaged after exposure to 1 million pulse of 1.3 mJ x-rays at 300 eV. Close examination under a microscope confirmed that there was no detectable damage at this dose level. More detailed measurements of the B4C damage threshold were performed with focused x-rays in the SXR instrument [6]. The B4C single pulse damage threshold was determined to be 0.49 eV per atom +/-0.08 eV. At 0.16 eV per atom there was no damage after 640,000 pulses. From these data it was determined that 60,000 of these pulses produced a dose level of 0.18 eV per atom.

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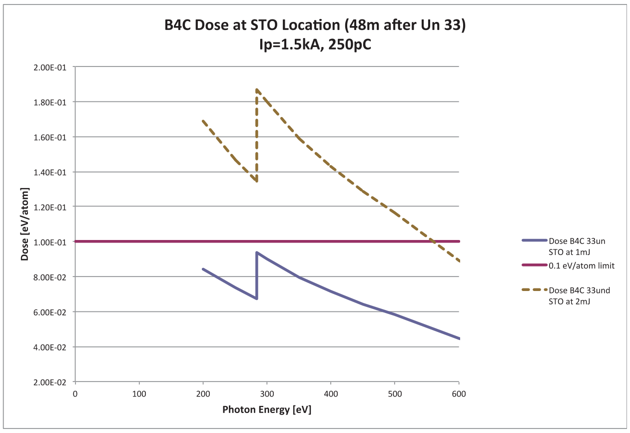

Figure 7: Dose calculation for 33 undulators at STO for two different pulse energies: 1 mJ and 2 mJ.

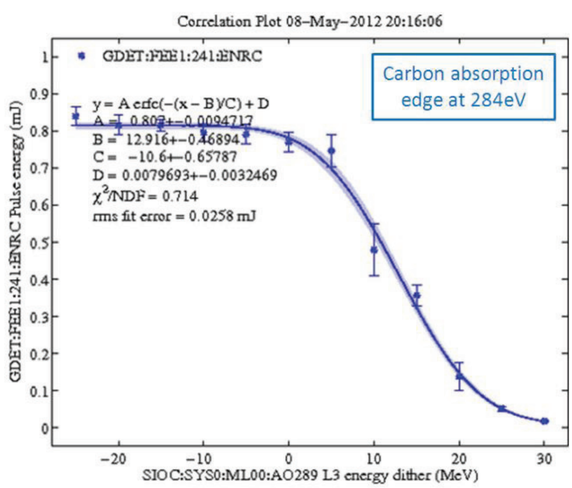

Figure 8: FEL wavelength confirmed by scan across the carbon absorption edge at 284 eV.

Figure 9: B4C sample after exposure to 1 million pulses of 300 eV x-rays.

PRESENT STATUS

The LCLS has delivered x-rays below 300 eV to both the AMO and SXR instruments. This energy range is now available to users subject to approval by LCLS and the responsible instrument scientist. At the 284 eV carbon edge the typical pulse energy is 0.5 mJ but if given time (1-2 hrs) can frequently exceed this. Figure 10 shows the measured LCLS FEL energy over the entire available wavelength range.

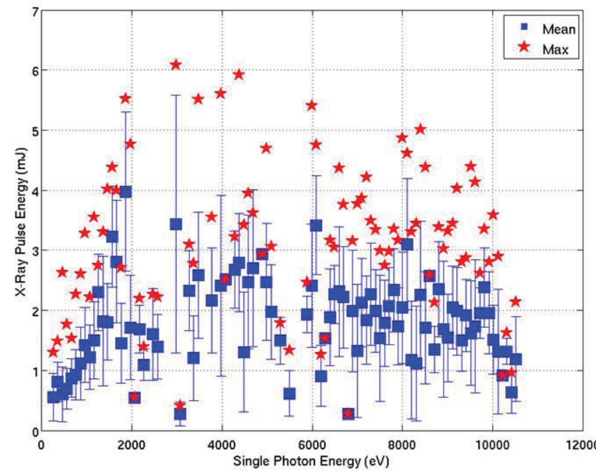

Figure 10: Measured LCLS FEL energy vs. photon wavelength.

CONCLUSIONS

To date, commissioning LCLS low-energy capability down to 250 eV has been quite smooth which demonstrates the strength of the design model. The original LCLS x-ray energy range was from 830 to 8300 eV. Many of the options available at higher energy, such as <10 fs bunch length, harmonic generation and two color x-rays will be made available at low energy. One parameter that exceeds the capability of the specification is the x-ray beam size in the x-ray transport system and the soft x-ray offset mirror system. The long-wavelength photon beam fills the available aperture such that the edges of the beam are blocked. The x-ray transport system is under review to determine the cost and benefit of increasing the aperture in this area.

ACKNOWLEDGEMENTS

Many people contributed to the success of LCLS FEL delivery from 250 to 500 eV. Paul Emma set the standards and methods to “do it right.” Stefan Moeller, Jacek Krzywinski, Regina Soufli and her team provided critical analysis of boron carbide stopper material. John Galayda and Uwe Bergmann provided leadership, encouragement and vision. This project would not have been so successful without the unrivalled skill of the LCLS MCC accelerator operators, EOICs and staff.

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