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LCLS-II INJECTOR COMMISSIONING BEAM BASED MEASUREMENTS*

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Abstract

Injector commissioning is underway for the LCLS-II MHz repetition rate FEL, currently under construction at SLAC. Methodology of injector beam-based measurements and early results with low beam charge will be presented, along with the software tools written to automate these various measurements.

INTRODUCTION

LCLS-II is an upgrade to the existing LCLS Free Electron Laser, and is currently being installed at SLAC National Accelerator Laboratory. LCLS-II is a MHz repetition rate 1.3 GHz superconducting linear accelerator currently being installed in the first third of the existing 3 km accelerator tunnel. It will complement the existing normal-conducting 2856 MHz copper linear accelerator currently occupying the last third of the tunnel. Two new undulator lines are being installed, each utilizing variable gap undulators. Fed with electron beam from either the copper or superconducting accelerators, these undulators will enable the generation of hard and soft X-rays at energies ranging from 0.2 to 25 keV. Figure 1 gives an overview of the LCLS-II upgrade.

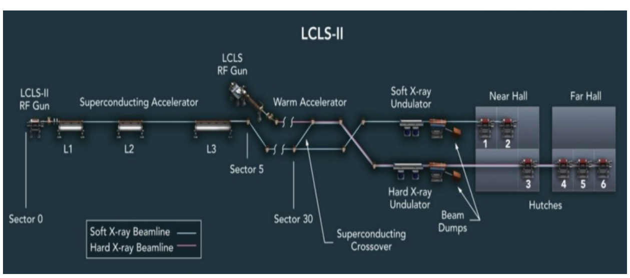

Figure 1: Schematic of LCLS-II upgrade.

INJECTOR SOURCE

The injector source for LCLS-II is currently installed and comprises approximately 2 meters of beamline. There are several important components of the injector source:

- 186 MHz CW normal conducting electron gun.
- 1.3 GHz CW normal-conducting buncher.
- Two moveable solenoids.
- Five horizontal and five vertical corrector dipoles.
- YAG screen for transverse profile measurements.
- Two stripline beam position monitors.
- One toroid.
- A faraday cup (measures charge and average current).

A Cesium-Telluride coated cathode inside of the electron gun produces electron beam when struck by a UV laser with a wavelength of 257.5 nm. The gun accelerates this beam to 750 keV, where it is then longitudinally compressed inside of the buncher. The injector beamline, for the early injector commissioning phase of operation, terminates at a faraday cup located before the endcap for the first cryomodule. Figure 2 shows a detailed injector layout schematic.

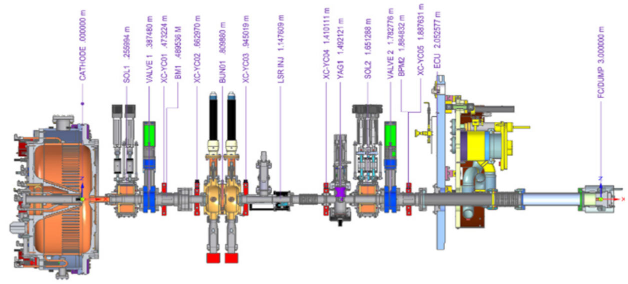

Figure 2: LCLS-II injector layout.

Nominal bunch charge is 100 pC, and the nominal peak current is 12 A. Emittance is expected to be on the order of 0.4 um-rad. Table 1 summarizes important injector source beam parameters [1].

Table 1: LCLS-II Injector Parameters

Parameter	Nominal
Gun energy (keV)	750
Bunch repetition rate (MHz)	0.93
Bunch charge (pC)	100
Peak current (A)	12
Slice emittance (μm*rad)	0.4

BEAM-BASED MEASUREMENTS

The LCLS-II injector source is currently in the early injector commissioning phase. In order to characterize this new source and precisely control the electron beam characteristics, a variety of beam-based measurements need to be repeatedly and reliably made. These measurements include:

- Electron gun electric field amplitude.
- Buncher electric field amplitude.
- Laser launch phase.
- Buncher phase.
- Laser alignment on cathode.
- Solenoid alignment.

As the LCLS-II injector source does not have a diagnostic line or dispersive region during this commissioning phase, a corrector dipole-based method has been employed as a means of making accurate energy and phase measurements.

Energy Measurement Method

A corrector is used to scan the electron beam position with several different field settings, and for each setting the

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beam position is measured on either the YAG screen or a beam position monitor. A linear fit is then performed of electron beam position (in meters) versus corrector strength (in kilogauss meters), which gives a slope. The kinetic energy of the beam can then be calculated using the following equation:

$$E_k = 0.511 \cdot 10^{-3} \cdot \left(\sqrt{\left(\frac{d}{33.356 \cdot 0.511 \cdot 10^{-3}} \cdot \frac{1}{\frac{x}{BL(kG.m)}} \right)^2 + 1} - 1 \right) \tag{1}$$

where BL is the integrated strength of the corrector, x is the beam displacement, E_k is the kinetic energy of the beam in GeV, and d is the distance between the corrector and the screen (or beam position monitor). The aforementioned slope is equivalent to x/BL.

Gun and Buncher Amplitude

To measure the gun energy, the buncher is turned off and beam position measurements are taken for several corrector settings. The slope of position versus corrector setting is plugged into equation 1 in order to calculate the energy. This method, with the YAG screen as a position measurement device, should be accurate enough to resolve energy differences of 10 keV [2]. Figure 3 shows simulated measurements of 750 keV and 760 keV electron beams in order to illustrate the estimated YAG resolution. BPM resolution should be capable of resolving 100um difference over the corrector range.

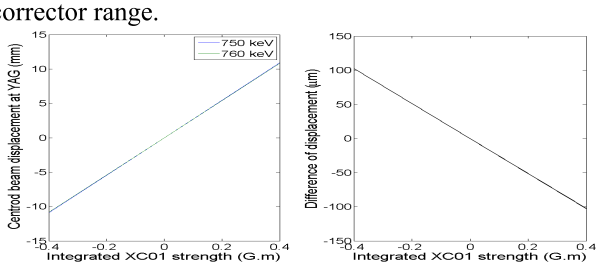

Figure 3: Simulated beam position versus corrector strength for both 750 keV and 760 keV (left), and difference between these positions versus strength (right).

To measure buncher energy, the buncher is powered on and the buncher phase is set to on crest. Beam position measurements are again taken for several different corrector settings, and the slope of a linear fit to this data is used with equation 1 to calculate the total energy of the gun and buncher combined. The gun energy is then subtracted out, leaving the measured buncher energy. Figure 4 shows a simulated measurement using the third horizontal corrector.

Laser Launch Phase

The gun RF phase in relation to the reference RF phase is fixed, but the laser needs to be precisely timed to fire at the proper gun phase. To measure the laser phase compared to the gun phase, bunch charge as a function of laser timing is measured. The zero crossing of the gun phase is found by scanning the laser timing until the electron charge is extinguished. The final laser phase is then set near-crest for nominal electron beam generation. Figure 5 shows a simulated laser launch phase scan, using expected values for the LCLS-II gun.

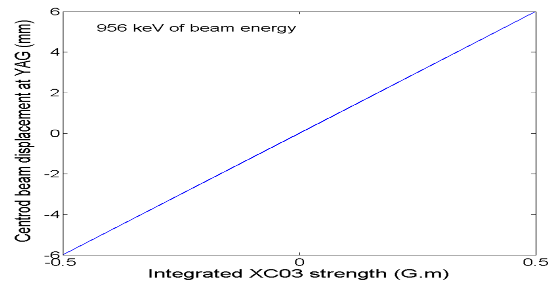

Figure 4: Simulated beam position versus corrector strength for buncher energy measurement.

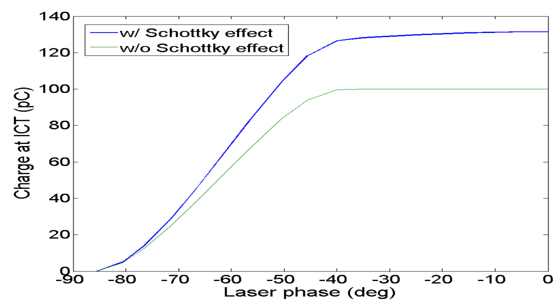

Figure 5: Simulated laser launch phase scan, with and without Schottky effect.

Buncher Phase

Normally, the electron beam passes through the buncher when the RF is at a zero crossing. There is no net energy gain, only a longitudinal compression of the beam. Therefore, it is possible to scan the buncher phase while looking at the beam energy in order to find a zero crossing. With the buncher powered, the phase is scanned until the beam energy matches the energy of the gun alone. Figure 6 illustrates this through a simulated measurement.

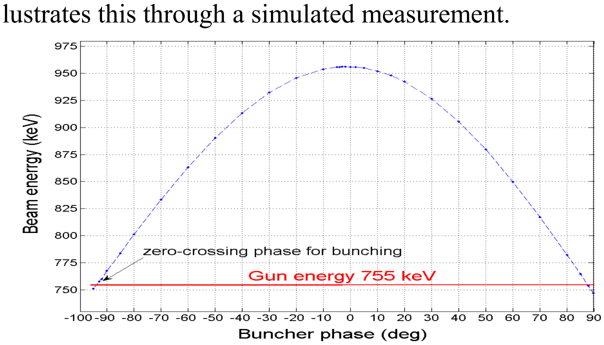

Figure 6: Simulated buncher phase measurement.

The proper zero crossing to achieve bunching of the electron beam can be determined by subsequently looking at the transverse beam size on the YAG screen for both zero crossings after either zero crossing is found. The beam size for the bunching zero crossing should be significantly larger. Figure 7 exhibits this fact.

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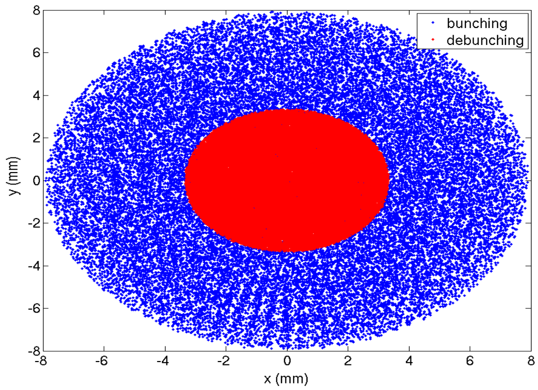

Figure 7: Simulated beam size at YAG screen for bunching and debunching zero crossings.

Laser Alignment on Cathode

The center of cathode measurement is relatively simple. The electron-producing Cesium-Telluride coating on the cathode is circular and has a 5mm diameter. If the UV laser strikes the cathode outside of this area, photoelectron beam will not be produced. Therefore, the laser position on the cathode is simply scanned in both the horizontal and vertical directions to find where charge production falls off. This defines four edges of the active cathode region and the center position can be inferred.

RESULTS

Low charge electron beam has been produced from the LCLS-II gun. Figure 8 shows this first beam.

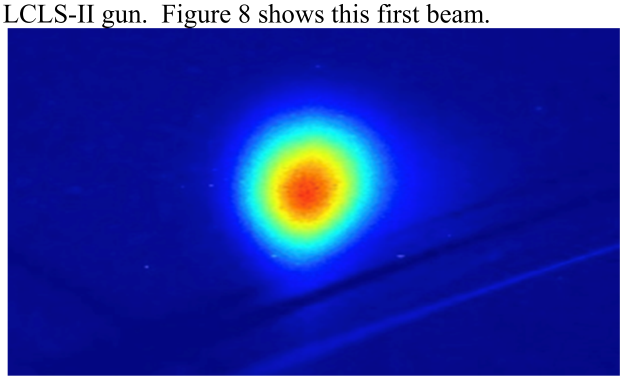

Figure 8: First electron beam from the injector source.

Shortly after making first photoelectron beam from the LCLS-II injector source, a successful manual measurement of the energy was made. The energy was measured to be 766 keV, nearly identical to the design energy of 750 keV. Following the manual measurement, an automated measurement was made which agreed with the manual measurement. Figure 9 shows an actual beam-based measurement of the electron gun energy, using the automated measurement method.

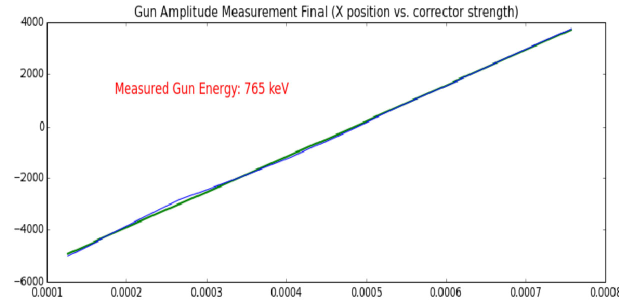

Figure 9: Beam-based measurement of gun energy. Y axis is horizontal beam position on YAG (in microns), X axis is XC03 corrector strength (in kG-m).

AUTOMATION

Beam-based measurements have been automated using Python. As noted above, the gun energy measurement has been successfully tested with recently produced electron beam. Other automated measurements will be tested shortly. Graphical user interfaces have been developed for these automated measurement algorithms. Figure 10 shows these interfaces.

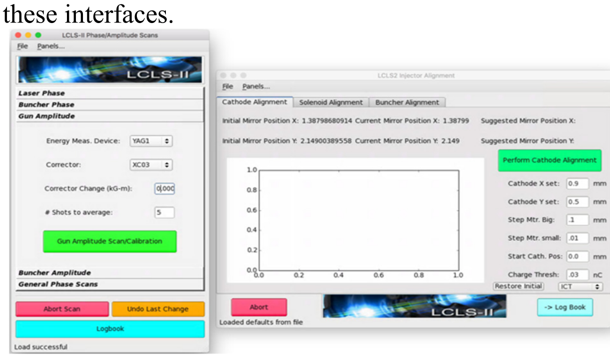

Figure 10: User interfaces for automated measurements.

CONCLUSION

LCLS-II injector commissioning is underway at SLAC, and beam-based measurements are now being made. The gun energy has been successfully measured, both through manual and automated means. Automation has been implemented for many different measurement types and will be tested as injector commissioning progresses.

ACKNOWLEDGEMENTS

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