TUNING OF THE LCLS LINAC FOR USER OPERATION*

J. Rzepiela, H. Loos†, R. Akre, A. Brachmann, F.-J. Decker, Y. Ding, P. Emma, A. Fisher, J. Frisch, S. Gilevich, P. Hering, Z. Huang, R. Iverson, N. Lipkowitz, H.-D. Nuhn, D. Ratner, T. Smith, J. Turner, J. Welch, W. White, J. Wu, G. Yocky, SLAC, Menlo Park, CA 94025, USA

Abstract

With the Linac Coherent Light Source (LCLS) now in its third user run reliable electron beam delivery at various beam energies and charge levels has become of high operational importance. In order to reduce the beam tuning time required for such changes, several diagnostics and feed-forward procedures have been implemented. We report on improved lattice diagnostics to detect magnet and model errors as well as on measurements of transverse RF kicks and static magnetic field contributions and corresponding correction procedures to facilitate beam energy changes.

INTRODUCTION

The LCLS facility at the SLAC National Accelerator Laboratory is the first free electron laser operating at angstrom wavelengths [1] (see Fig. 2). A typical schedule during user runs has 5 days per week dedicated to user experiments in two 12-hour shifts per day. The LCLS has operated with photon energies from 480 eV to 9.6 keV. Additionally, bunch charge can be varied from 250 pC (yielding a FWHM pulse duration of 70-300 fs) to 20 pC (yielding <10 fs FWHM pulse duration). With this wide range of operating conditions and the need to reconfigure the linac between and/or during each shift, much effort has been placed on developing diagnostics to allow operators to effect these changes quickly and consistently [2, 3]. The latest diagnostics to be added focuses on comparing the measured and modeled orbit response to scanning of a corrector magnet and measurements of transverse kicks due to the accelerator klystrons and of static fields.

ORBIT RESPONSE MEASUREMENTS

The LOCO (Linear Optics from Closed Orbits) method can be used to accurately calibrate the linear optics of a storage ring using the change in orbit at beam position monitors (BPMs) in response to changes in steering magnets [4]. Normal and skew gradients of quadrupoles, gains and cross-coupling in BPMs, and strengths and rotations of steering magnets can all be determined. A new MATLAB diagnostic has been developed for use in the LCLS accelerator to scan a given corrector magnet and measure the resulting orbit change as measured by downstream BPMs. The measured orbit response is compared to an online model. A fitting procedure determines the corrections required to improve the match between the modeled and experimental response.

* Work supported by US DOE contract DE-AC02-76SF00515.
† loos@slac.stanford.edu

Graphical User Interface (GUI)

The GUI for the orbit response diagnostic is shown in Figure 1. Any sector of the linac and beam transport lines can be selected using the push buttons in the upper left corner of the GUI. Choosing a particular sector automatically populates the lists of X and Y corrector magnets and BPMs with devices found in that sector. Sector boundaries are spanned by including several BPMs from the following linac section. The maximum orbit excursion can be specified (subject to machine protection constraints) along with the number of different corrector magnet settings desired. A specified number of BPM readings are obtained with a specified delay between each reading.

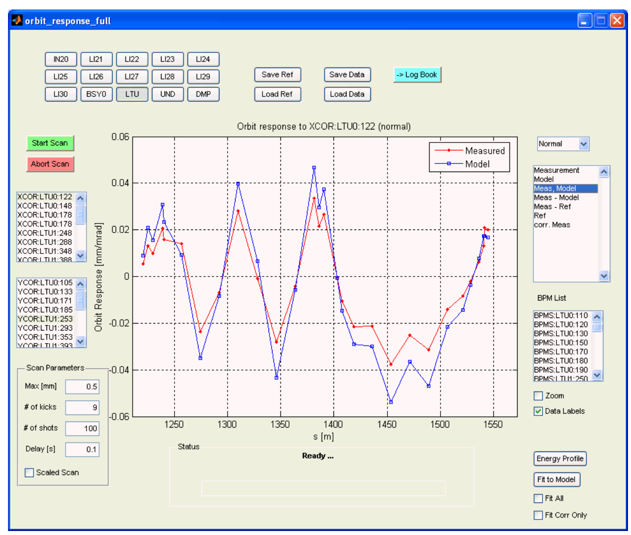

Figure 1: Orbit Response Diagnostic GUI.

Several display options are available. The display can show an overlay of the measured orbit response to that predicted by the online model for either the in-plane or skew response. Alternatively, the difference between the values can be plotted. Another option is to plot the orbit response for a single BPM vs. the magnitude of the corrector kick to examine the linearity of the response and the magnitude of the error bars for the measurement.

Optimization Procedure

A fitting routine is used to improve the match of the experimental and modeled orbit response. In a full fit, data from all corrector scans are used and the gain corrections (g_x, g_y) and rotation angles (ϕ) for all correctors,

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)

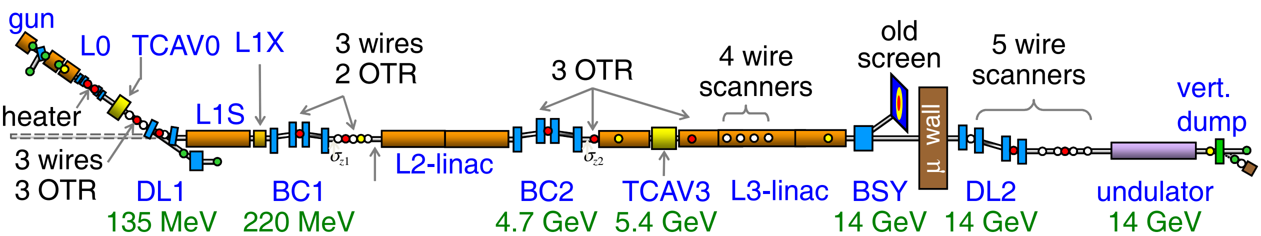

Figure 2: Layout of the LCLS accelerator.

quadrupoles, and BPMs are determined according to:

$$\begin{pmatrix} x' \\ y' \end{pmatrix} = \begin{pmatrix} \cos\phi & \sin\phi \\ -\sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} g_x x \\ y_y y \end{pmatrix}$$

Alternatively, BPM data from a scan of a single corrector can be used to determine the gain corrections for that corrector. The advantage of having this mode is that the time required for the fit to converge is reduced. Having determined the gain corrections required, BPM data from a second scan of the corrector can be obtained, scaling the output of the corrector magnet by the newly determined gains (by choosing the "Scaled Scan" option in the GUI). Assuming the fit has converged to the correct value, the match to the model for this second scan will be improved, providing immediate feedback to the operator that a particular component requires recalibration.

Results

Data collected by scanning all correctors in the linac-to-undulator (LTU) sector were obtained at 3.454 and 13.6 GeV. A full fit of data from all scanned correctors was performed at each energy. A representative example of the improvement in the match between the measured and modeled orbit response at 3.454 GeV is shown in Figure 3.

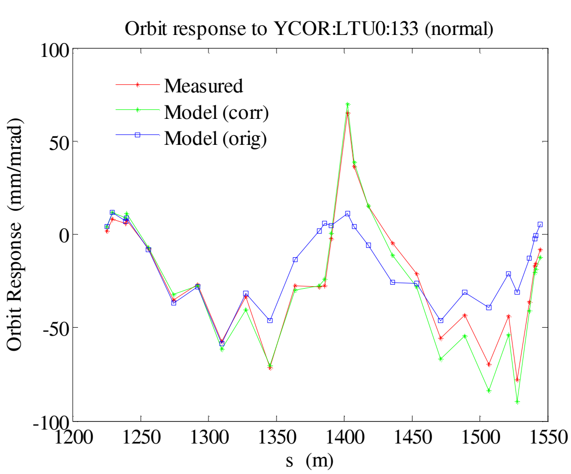

Figure 3: Fitting results (3.454 GeV).

In order to check for consistency in the determined coefficients, data from 3.454 and 13.6 GeV were fit separately. Table 1 shows a sampling of the coefficients determined for several Y correctors. The data show a consistency between the values determined at low and high energies. Some correctors exhibit up to 25-30% reduction in gain compared to the calibrated value (i.e. the magnet values would have to be increased to match the orbit change predicted by the online model). Independent measurements of R matrix values obtained by manually scanning correctors in this region are consistent with gain values from the fitting procedure. The magnitude of the discrepancy is surprising since all corrector magnets were bench measured prior to installation.

Table 1: Fit coefficients for Y correctors

	3.454 GeV		13.6 GeV	
Corrector	**Angle**	**Gain**	**Angle**	**Gain**
YCVM1	0.002	0.852	0.002	0.854
YCVB1	-0.082	0.969	-0.082	0.970
YCVB3	-0.014	0.933	-0.014	0.934
YCVM4	0.097	0.762	0.096	0.768
YCDL1	-0.093	0.937	-0.095	0.914
YCQT12	-0.299	0.789	-0.298	0.792
YCDL2	0.073	0.670	0.071	0.700
YCQT22	0.188	0.757	0.192	0.732

RF KICK AND STATIC FIELD MEASUREMENTS

The operating energy of the LCLS accelerator within the range from 3.3 to 14.7 GeV is selected by successively triggering RF structures of the last 600 m of the linac (L3). Although all magnets are scaled to the actual energy profile of the machine during changes of the final beam energy, many steering correctors need to be tuned to maintain the desired orbit. One contribution is transverse kicks from the RF structures which result from asymmetric RF couplers.

Figure 4 shows in the top part an example of difference orbits averaged over 50 beam pulses at 0° and 180° phase of one RF structure located at 700 m with the reference orbit taken with the same structure turned off. The equivalent strength of a corrector at the very end of the structure is determined by a fit to the orbit. To account for changes in the beam energy downstream of the RF structure as the phase is

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)

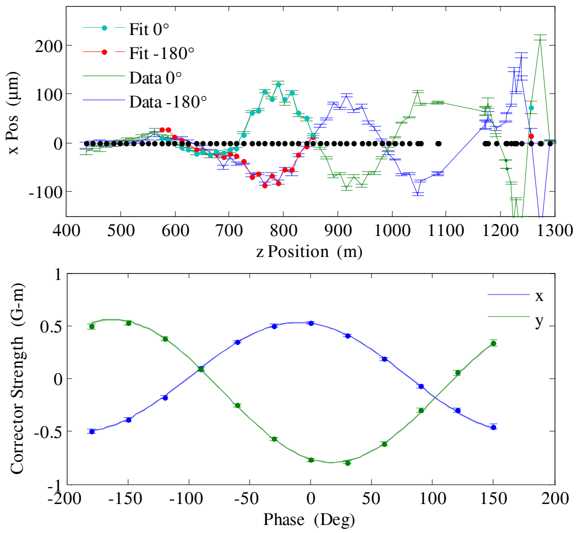

Figure 4: RF transverse orbit kick. Upper plot shows for the RF structure at 700 m the difference orbits for two phase settings w.r.t. structure off. Lower plot shows corresponding corrector strength for x & y plane vs. RF phase.

changed all magnet strengths are adjusted accordingly for each phase setting. The lower part shows the kicks vs. RF phase and sinusoidal fits to the data. Such measurements have been performed for all 48 12-m long RF structures in the L3 linac and show random amplitude and phase distribution of the kicks among them with an rms amplitude of 0.75 G-m. This corresponds to betatron oscillations of up to 400 μm from turning on a single RF station. An automatic correction scheme to facilitate changes in the electron beam energy is being developed to adjust the corrector magnets in the main linac to compensate these kicks depending on klystron complement and RF phases.

A second contribution to beam orbit changes due to changing the beam energy stems from static magnetic fields. These fields comprise of the earth's magnetic field in the 500 m long beam transport line from the end of the linac to the LCLS undulator and remnant fields from turned off magnets as well as from a 17 m long iron muon shield wall in the beam switch yard (BSY) downstream of the linac. As during energy changes the strength of all magnets in the beam line is scaled with the beam energy by the linac energy management (LEM) software, the a priori unknown static fields cannot be scaled and will such change the beam orbit. Subsequent steering by hand and from feedbacks to regain the desired orbit will then distribute the effect from the static fields onto nearby correctors.

Figure 5 shows the strength of 3 horizontal and vertical correctors in the BSY as a function of electron beam energy. During the measurements the linac energy was slowly ramped up from 4.3 to 14.3 GeV while some manual steering and the transverse feedback loops kept the beam within less than 1 mm to the original reference orbit. The corrector

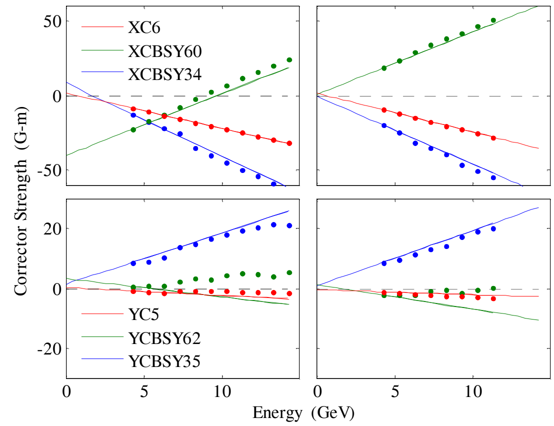

Figure 5: Beam-based static magnetic field measurement. Horizontal and vertical correctors are shown in the top and bottom panels. The panels on the left and right show the measurements before and after applying static offsets to the corrector magnets. Actual corrector strengths are dots and the solid lines are from fits to the measured orbits.

strengths of the initial measurements shown in the panels on the left exhibit a linear but not a proportional relation to beam energy and extrapolations to zero energy correspond to the equivalent static field strengths. The solid lines are obtained by fitting both fixed and energy proportional corrector strengths simultaneously to all measured orbits while minimizing the deviations from the reference orbit taken at the lowest energy. For the measurements shown on the right panels in Fig. 5 the static field values obtained from the fit were implemented as fixed offsets in the corrector power supply currents so that the proportional energy scaling from the LEM software could maintain the beam orbit.

SUMMARY

Recent additions to the suite of diagnostics developed for LCLS have been described. Orbit response measurements can be made by scanning corrector magnets throughout the linac. A fitting procedure determines the required corrections to angles and gains for beam line components to better match modeled orbit response. Measurements of transverse kicks from RF structures and beam-based static magnetic field measurements can be used to better predict necessary steering during beam energy changes. These new diagnostics are part of an ongoing effort to provide tools used by operators to reconfigure the linac quickly and in a repeatable manner for a wide range of user experiments.

REFERENCES

[1] P. Emma et al., Nature Photonics 4 (2010) 641.

[2] H. Loos et al., Proceedings of BIW 2010, Santa Fe, NM, May 2010, p. MOIANB01 (2010).

[3] N. Lipkowitz et al., WEOBS4, these proceedings.

[4] J. Safranek, Nucl. Instr. and Meth. A 388 (1997) 27.

Copyright © 2011 by PAC'11 OC/IEEE — cc Creative Commons Attribution 3.0 (CC BY 3.0)