

## LCLS UNDULATOR SYSTEM TUNING AND MAGNETIC MEASUREMENTS\*

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### Abstract

The LCLS project at SLAC requires 40 undulators: 33 in the beam line, 6 spares, and one reference undulator. A new facility was constructed at SLAC for tuning and fiducializing the undulators. The undulator tuning has been partially automated. Undulator and quadrupole fiducialization techniques have been devised. The new facility, the tuning techniques, and the fiducialization techniques will be discussed.

### INTRODUCTION

The Linac Coherent Light Source (LCLS) at SLAC consists of 33 segments forming a 120 meter long undulator for a free electron laser. Each segment is a fixed gap planar hybrid undulator utilizing NdFeB magnets. The undulator period is 3 cm and the K value varies from 3.500 to 3.493 to account for beam energy loss. With electron energy of 13.64 GeV, the radiation wavelength will be 1.5 Å.

A new laboratory was constructed at SLAC to tune the undulators. The temperature stability of the laboratory is 0.1 C to allow setting the K values to  $1.5 \cdot 10^{-4}$ . This paper describes the laboratory and the techniques employed to tune and fiducialize the undulators. It also describes the measurements and fiducialization of the quadrupoles between the undulators.

### UNDULATOR TUNING

The undulators are tuned in two steps using two separate test benches. This allows work to proceed in parallel. A rough tuning is first performed in which the K value is set and a magnetic shield is placed on the undulator. The undulator is then moved to the fine tuning bench where a more extensive set of instruments allows final adjustments to be made and checks to be performed.

#### Rough Tuning

The rough tuning of an undulator begins by placing the undulator on the bench and positioning it so that the probes do not contact the undulator. A set of 6 capacitive sensors is then used to measure the position of the undulator along its length and a cam mover system [1] aligns the undulator to the bench based on the capacitive sensor measurements. Five degrees of freedom are adjusted, with the remaining longitudinal position being only measured. The process requires 2 or 3 iterations and is completed in approximately 15 minutes.



Figure 1: Rough tuning bench showing an LCLS undulator on the cam mover system.

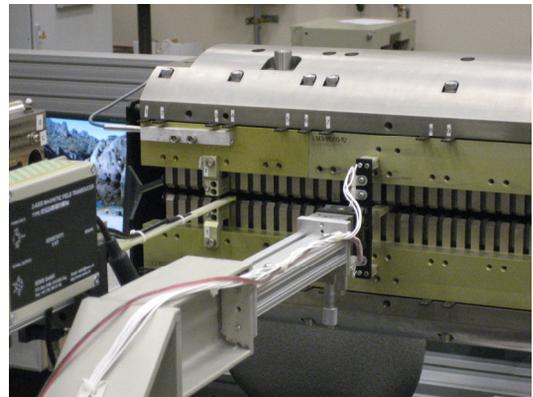


Figure 2: Capacitive sensors (right) and Hall probe (left) moving through an LCLS undulator.

A Hall probe is mounted on vertical and horizontal stages secured on a carriage which moves down the bench. We use Sentron XZM12-3-0.6-2T Hall probes because of their low electrical noise and small planar Hall effect. To align the Hall probe to the undulator, horizontal and vertical scans are made at poles periodically down the undulator. The minimum of the field vertically and the symmetry point horizontally define the magnetic center at that pole. A fit is made to the magnetic centers. The cam movers remove any magnetic pitch or yaw and the probe is moved horizontally and vertically to align it to the magnetic axis of the undulator.

Once the alignment is done, scans of the magnetic field in the undulator begin. Beam trajectories are calculated. A computer program was written to specify shim locations and strengths to straighten the trajectory. The types of shims used are described in [2]. The algorithm [3] the program uses fits the trajectory with a number of straight line segments. This averages the trajectory and turns the problem into a discrete problem of segments rather than a continuous one. A matrix inversion gives

**Magnets**

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the slope change of each segment required to make the trajectory straight. A parameterization gives the shim strength required for each slope change. This procedure gives one shim per segment. In order to reduce their number, shims are combined such that the trajectory tolerances are not exceeded.

After the horizontal and vertical trajectories are straight, the phase and K value are calculated. Tapered shims down the length of the undulator are used to adjust the gap such that phase errors are reduced and K is set to the desired value. The tapered shims adjust the gap when moved horizontally [4]. This is illustrated in figure 3. Shims on the magnets further reduce phase errors and are used to perform phase matching at the ends of the undulator.

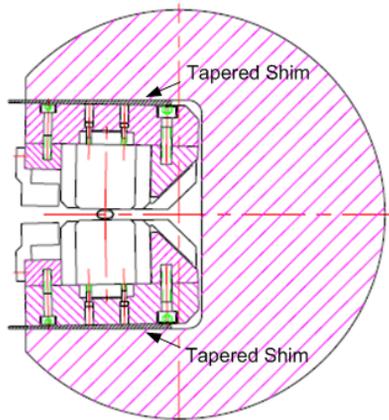


Figure 3: Tapered shims are moved horizontally to adjust the undulator gap.

Once the undulator is tuned and the K value is set, a magnetic shield is placed around the undulator. Corrections to the measurements anticipating the shield have been made up to this point. The corrections are removed and any required adjustments to the shims are made. This completes the rough tuning. The bolts used to set the gap and adjust the K value are no longer accessible once the magnetic shield is in place.

### Fine Tuning

After rough tuning, the undulator is moved to the fine tuning bench. The undulator support consists of a steel girder and steel pedestals as used in the tunnel, with the same orientation to minimize differences in external fields. The undulator is aligned to the bench using capacitive sensors and cam movers as discussed previously. The Hall probe is aligned to the undulator using the same technique as for rough tuning.

Under these conditions better simulating the tunnel, a final tuning of trajectories and phase is made with the Hall probe. Short coils one period long are used to check the Hall probe measurements. The field integrals are set using a long coil [5]. The coil is built using a strongback which supports 150 turns of wire in the gap. The first and second field integrals of both the vertical and horizontal fields are measured. When all the measurements are

made and the undulator is tuned within tolerance, the shims are glued in place. The trajectories and the K value are checked and a final dataset of results is made.

### Fiducialization

The tapered shims give the undulator poles a 4.5 mrad cant angle. Hall probe scans are made at different horizontal positions and K is determined at each position. The location where K has the desired value is determined by a fit and the Hall probe is placed at that position. The Hall probe path is on the ideal beam axis.

To fiducialize the undulator, magnets with conical poles of the same sign are attached to each end of the undulator as shown in figure 4. The fiducialization magnets have a zero field point which can be found with high repeatability. The location of this point is known relative to tooling balls through a calibration procedure [6].

The Hall probe is first moved from the beam axis to the fiducialization magnet zero point at each end of the undulator and the distances are recorded. The distances from the fiducialization magnet's zero points to tooling balls on the fiducialization magnets are known through the calibration. The offsets from the tooling balls on the fiducialization magnets to tooling balls on the undulator are measured with a coordinate measuring machine. The sum of these numbers gives the offset from the ideal beam axis to tooling balls on the undulator at each end of the undulator. An alignment crew performs an optical check of the results.

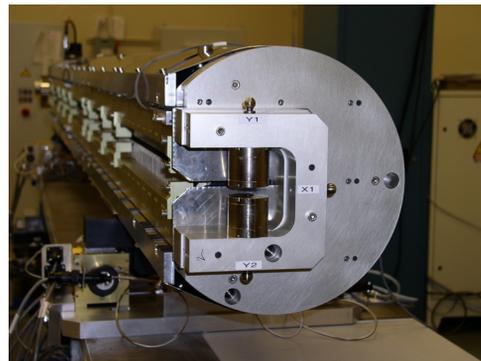


Figure 4: Magnets are placed on the ends of the undulator for the fiducialization.

## UNDULATOR QUADRUPOLES

### Magnetic Measurements

An electromagnet quadrupole is placed between neighboring undulator segments in the beam line. The strength and harmonics are measured as a function of current with a rotating coil for each quadrupole [7]. The position of the magnetic center during 20% variations in the field strength is measured for use in beam based alignment. Finally, the coil is used to measure the strengths of the dipole trim windings and the position of the magnetic center after the dipole trim windings are energized to see whether hysteresis effects might cause beam steering.

### *Fiducialization*

The quadrupoles are fiducialized using a vibrating wire system [8] built on a coordinate measuring machine. The setup is shown in figure 5. The quadrupole is moved in transverse position and in pitch and yaw angles using cam movers. Measurements are made of wire vibration amplitude and phase as a function of magnet transverse position and angular orientation. The second and fourth wire vibration harmonics are used to minimize the effect of the Earth's field. The fitted measurements are used to determine the vibration null point, which occurs when the magnetic axis is aligned with the wire. The coordinate measuring machine then determines the wire position and tooling ball positions on the quadrupole, completing the fiducialization.



Figure 5: Quadrupole fiducialization system using a vibrating wire and a coordinate measuring machine.

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<sup>†</sup> LCLS Technical Notes are available at [www-ssrl.slac.stanford.edu/lcls/lcls\\_tech\\_notes.html](http://www-ssrl.slac.stanford.edu/lcls/lcls_tech_notes.html).