LCLS-II Phase Shifter Test Plan

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Abstract

This note presents the test plan for the LCLS-II hard x-ray and soft x-ray phase shifters. The phase shifters were tuned at Danfysik. This note pertains to measurements required to make a final data set at SLAC. The requirements for the measurements are summarized. A brief discussion of the measurement equipment is presented. This is followed by the detailed test plan in which each step is enumerated. Finally, the measurement results and data storage format are presented.

1 Introduction[1]

The LCLS-II will have 33 undulator segments for the hard x-ray line (HXR) and 22 undulator segments for the soft x-ray line (SXR). Between each pair of undulator segments, there is a phase shifter which synchronizes the electron beam motion to a light wave in the undulator segments. The required 53 phase shifters plus spares are being built at Danfysik. Danfysik is tuning, and fiducializing them. In order to meet the accuracy requirements, a final set of measurements and a final fiducialization will be made at SLAC.

The plan for measuring the final data set for the phase shifters is very similar to the plan for measuring the final data set for the LCLS-II undulators[2]. A reference phase shifter of each type will be selected and measured at frequent intervals in order to guarantee consistency of the measurements. The Hall probe used for the measurements will be frequently calibrated and the calibration will be checked in a reference dipole located on the test stand. Phase shifters which have been measured will periodically be brought back for repeat measurements to verify that the phase shifters are not changing due to storage conditions.

The note begins by describing the laboratory in which the work will be performed and the relevant equipment used for the measurements. The list of measurement and fiducialization requirements is presented. This is followed by a detailed test plan in which all the steps of the measurements and fiducialization are enumerated.

[1]Work supported in part by the DOE Contract DE-AC02-76SF00515. This work was performed in support of the LCLS project at SLAC.

[2]Z. Wolf, et al., "LCLS-II Undulator Test Plan", LCLS-TN-17-1, August, 2017.

2 Measurement Facilities

The SLAC magnetic measurements group has a granite bench ("Dover" bench named after its manufacturer) for making the phase shifter measurements. The Dover bench is located in the Magnetic Measurement Facility (MMF) in a laboratory at the edge of the building. The laboratory has 2 °C temperature stability at a set point variable from 17 °C to 23 °C. The current temperature stability will be a problem for these measurements as large temperature corrections to the tunnel temperature of 20.0 °C will be required. We are currently working with the Facilities department to improve the temperature stability. If this effort is unsuccessful, the measurements will take place during the night when the temperature is more stable and closer to 20.0 °C.

Proper phase shifter handling infrastructure will be provided such as a movable crane. Proper laboratory equipment is provided such as a complete set of instruments, calibration equipment, etc. Hall probe calibrations are done in the main laboratory of the MMF. Storage space for receiving phase shifters and for storing them until they are needed for installation is provided adjacent to the MMF. Storage space for the reference phase shifter will be provided in the CMM area of the MMF.

3 Earth's Field

The Dover bench orientation is parallel to the undulator lines, but the phase shifters can only be measured on one side. The HXR phase shifters will be measured with the same orientation they will have in the tunnel, but the SXR phase shifters will be rotated 180 degrees from their measurement orientation. This will introduce an error in the horizontal component of the magnetic field. In order to eliminate this error, the Earth's magnetic field will be subtracted from the measurements. The Hall probe measurements outside the phase shifter will be averaged and the average field will be subtracted from the phase shifter field measurements. In this way, only the fields from the phase shifter will be used in the results. The effect of the Earth's field in the tunnel will need to be corrected with beam based techniques.

4 Measurement Requirements

The LCLS-II phase shifter tuning and fiducialization requirements come from a Physics Requirements Document[3]. The list of tuning and fiducialization requirements are briefly summarized below.

4.1 HXR Requirements

The requirements below must be met for all gaps in the operating range of 10 to 30 mm. Additionally, the field integral tolerances given below must be met for all horizontal and vertical positions within ±1.0 mm of the phase shifter beam axis at all gaps from 10 to 100 mm. The phase integral tolerances must be met on the beam axis.

[3] H. D. Nuhn et al., "Undulator Phase Shifter", LCLS-II Physics Requirements Document LCLSII-3.2-PR-0105-R1.

1. The phase change of the phase shifter must be accurate to 2.9° at all operational gap settings. Equivalently, the phase integral of the phase shifter must be accurate to 0.67 T^2mm^3. The phase integral will be measured at a discrete set of gaps. A fit to the measured phase integral vs. gap data must allow the phase integral at intermediate points to be known within the tolerance given here. This requirement sets the density of the measurements as a function of gap.

2. The first field integral of B_x and B_y must be within $\pm 20 \times 10^{-6}$ Tm. The second field integral of B_x and B_y must be within $\pm 45 \times 10^{-6}$ Tm^2.

3. The phase shifter temperature at which all measurements are performed must be 20.0 ± 0.5 degrees Celsius.

4. The position of the beam axis must be known to ± 50 μm in y and ± 200 μm in x relative to tooling balls on the phase shifter.

4.2 SXR Requirements

The requirements below must be met for all gaps in the operating range of 10 to 30 mm. Additionally, the field integral tolerances given below must be met for all horizontal and vertical positions within ± 1.0 mm of the phase shifter beam axis at all gaps from 10 to 100 mm. The phase integral tolerances must be met on the beam axis.

1. The phase change of the phase shifter must be accurate to 5.8° at all operational gap settings. Equivalently, the phase integral of the phase shifter must be accurate to 3.23 T^2mm^3. The phase integral will be measured at a discrete set of gaps. A fit to the measured phase integral vs. gap data must allow phase integral at intermediate points to be known within the tolerance given here. This requirement sets the density of the measurements as a function of gap.

2. The first field integral of B_x and B_y must be within $\pm 20 \times 10^{-6}$ Tm. The second field integral of B_x and B_y must be within $\pm 45 \times 10^{-6}$ Tm^2.

3. The phase shifter temperature at which all measurements are performed must be 20.0 ± 0.5 degrees Celsius.

4. The position of the beam axis must be known to ± 50 μm in y and ± 200 μm in x relative to tooling balls on the phase shifter.

4.3 Operational Requirements

We impose the following operational requirements.

1. The reference phase shifter must be measured and fiducialized after every 4'th phase shifter. At this time, the alignment of the measurement bench must also be checked.

2. A reference magnet at the bench must be measured with the Hall probe and this measurement compared to an NMR measurement before each final data set. The Hall probe must be recalibrated when its measurement relative to the NMR changes by more than 1×10^{-4}.

3. After measurements, the phase shifters will be stored until they are placed in the tunnel. Every three months, a phase shifter must be returned from storage and inspected and measured to verify that the storage conditions are not altering the phase shifter. Temperature and humidity must be logged in the phase shifter storage area.

4. After all phase shifters are measured, one phase shifter of each type will remain in the lab for a temperature test. The phase integral value will be measured over the range 18 $°C$ to 22 $°C$ in 1 $°C$ steps. These measurements will be used to determine corrections to the gap settings for tunnel temperatures different than 20.0 °C.

5. One phase shifter of each type will be transported to the LCLS-II tunnel and then returned to the MMF for re-measurement. This test is to ensure that phase shifter handling practices do not change the calibration.

5 Test Plan

5.1 Overview

The phase shifters were measured, tuned, and fiducialized at Danfysik. The Danfysik measurements show that the phase shifters meet the SLAC specifications. The Danfysik measurements, however, do not agree with SLAC measurements and the fiducialization is not to the magnetic axis. This makes the alignment requirements more severe than originally planned for. The Danfysik measurements will be used for initial setup of the phase shifter.

Hall probes will be used for the magnetic measurements. A long coil or flip coil will not be used for overall field integral and field integral uniformity measurements. The phase shifters are short and the Hall probe offsets will be stable over the short measurement time. Any Hall probe offsets will be subtracted during the Earth field removal which uses measurements in the same scan but outside the phase shifter.

The phase shifter fiducialization will occur at the Dover bench using a laser tracker. A set of fiducialization magnets on a stand at the end of the phase shifter will be used to determine the Hall probe position.

A vertical field alignment magnet is used to set the probe angles. A vertical field reference magnet is used to check the Hall probe calibration. Each Hall probe measurement starts in a zero Gauss chamber and ends in a zero Gauss chamber. There is minimal field in these chambers, so any non-zero reading is due to offsets in the probe electronics. A linear fit is made to the beginning and end measurements in the zero Gauss chambers and the fit is subtracted from the measurements in the phase shifter as a zero offset correction. The Earth's magnetic field will be measured in the region between the zero Gauss chambers and the phase shifter. The average Earth field will be subtracted from the field measurements. The pure permanent magnet phase shifter will allow the Earth field to go through it with minimal perturbation. In this way, only the phase shifter magnetic fields will be analyzed.

5.2 Test Plan

1. Preliminaries

   (a) All phase shifters must have their limit switch positions set and their encoder offsets set before measurements begin. The phase shifter must be protected and functional.

   (b) The phase shifter must be at 20 ± 2 °C when it is brought into the laboratory. During the setup time and initial measurements, the phase shifter must come to a temperature of 20 ± 0.5 °C.

2. Place the phase shifter

   (a) Bolt an SXR or HXR phase shifter to the stand at the Dover measurement bench.

   (b) Have the Controls group make all necessary wiring connections to operate the phase shifter. Test all limit switches.

   (c) Attach thermistors to measure temperature.

3. Mechanically align the phase shifter to the bench

   (a) Set the gap to the value Danfysik used to fiducialize the phase shifter.

   (b) Have an alignment crew position the phase shifter so that the Hall probe is on the axis that Danfysik fiducialized.

4. Find the magnetic axis

   (a) Define the Hall probe position to be $x = 0$, $y = 0$ on the fiducialized axis as determined by Danfysik.

   (b) Set the gap to 15 mm.

   (c) Measure the phase integral at $y = 0$, $x = -1, -0.5, 0, 0.5, 1$ mm.

   (d) Find the x-position of the maximum phase integral. Let this position be called x_0.

   (e) Measure the phase integral at $x = 0$, $y = -0.50$, -0.25, 0, 0.25, 0.50 mm.

   (f) Find the y-position of the minimum phase integral. Let this position be called y_0.

   (g) The position x_0, y_0 defines the magnetic axis relative to the axis that Danfysik fiducialized.

   (h) Translate the coordinate system so the new $x = 0$, $y = 0$ position is at the old x_0, y_0 position.

5. Final results data set

(a) Measure the phase integrals and field integrals in the good field region. Perform Hall probe scans and calculate the phase integral and first and second field integrals of B_x and B_y. Measure from $x = -1$ mm to $x = +1$ mm in 0.5 mm steps with $y = 0$. Measure from $y = -1$ mm to $y = +1$ mm in 0.5 mm steps with $x = 0$. Repeat this at gaps of 10, 12, 15, 20, 30, 100 mm. Place the data in the final results folder.

(b) Measure the phase integrals and field integrals on the phase shifter axis. Perform Hall probe scans and compute the phase integral and first and second field integrals of B_x and B_y. Measure at $x = 0$, $y = 0$. Measure at gaps from 10 mm to 30 mm in 1 mm steps, then at gaps of 35, 40, 45, 50, 55, 60, 70, 80, 90, 100 mm, and finally while closing the gap, measure at gaps from 30 mm to 10 mm in 1 mm steps. Place the data in the final results folder.

(c) Fiducialize the phase shifter. Have an alignment crew measure all tooling ball positions relative to the Hall probe measurement line. Verify that the change in tooling ball locations compared to the Danfysik values agrees with the x_0, y_0 change found above. Place the fiducialization data in the final results folder.

(d) Place all phase shifter operating parameters, such as encoder offsets, in a file in the final results folder. (All operating parameters must also be included in each measurement file.)

(e) Make files containing data for spline fits to be used by the control system to operate the phase shifter. The required files provide data for phase integral vs gap, I1x vs gap, I1y vs gap, I2x vs gap, and I2y vs gap. I1x refers to the first integral of the B_x field, I2x refers to the second integral, etc. Place these files in the final results folder.

6 Measurement Results

All raw data and analysis results will be available from the SLAC web site. The data will be stored in a directory structure as show in figure 1. The top level directory is *Magdata,* followed by *LCLS-II*, followed by the magnet type *Phase Shifter*. In the *Phase Shifter* directory, there is a folder for each phase shifter named by the serial number. There is also a folder which contains all the Danfysik measurement results. For each phase shifter, *Dataset* directories are made. When the phase shifter comes back for multiple measurements over time, each set of measurements goes into a new dataset. Within each dataset, the *Mechanical, Tuning, Fiducialization,* and *Final Results* folders are created. Since Danfysik has already measured and tuned the phase shifters, the *Mechanical, Tuning, Fiducialization* folders are optional and only the *Final Results* folder is required Each contains all the relevant measurements.

After any setup or tuning runs are complete, a special set of final measurement runs is made. The results from these runs will go into a "Final Results" folder. The contents of the "Final Results" folder are shown in figure 2.

For Hall probe scans, each measurement and its analysis results will go into a folder whose name is determined by the measurement number, the gap, and the x and y probe positions for the measurement. The fixed width format is "nnngapnnn.nnnxsnn.nnysnn.nn",

where "s" represents a sign, "." represents a decimal point, and "n" is a decimal digit. The initial "nnn" is used to give the measurement number. The gap and probe positions are in millimeters. All data files will be text files. All Hall probe measurement data files will be called "zscan.dat". In this way the analysis programs can be more easily automated so the contents of a folder are known in advance. Analysis results will be in both text files and either postscript plot files or PDF plot files.

The final positions of all the tooling balls on the phase shifter relative to the Hall probe axis will be placed in the *Fiducialization* folder. In this way the Hall probe axis will be on the beam axis when the phase shifter is placed in the tunnel.

The "Controls Data" folder contains files needed to operate the phase shifter. Each file has the serial number both in the contents of the file and in the file name. The Controls group will put the contents of these files into their database. The files contain the phase shifter parameters used during testing, and a set of data for spline fits relating the phase integral and the field integrals to the phase shifter gap.

7 Summary

SLAC will perform measurements for a final data set on the LCLS-II phase shifters. Hall probe measurements will be used to determine the phase integral and the field integrals both on the phase shifter axis and within the good field region. The Earth's field will be measured outside the phase shifter and subtracted from measurements in the phase shifter. A calibration will be performed to determine the temperature dependence of the phase integral. A transportation test to the tunnel will also be performed.

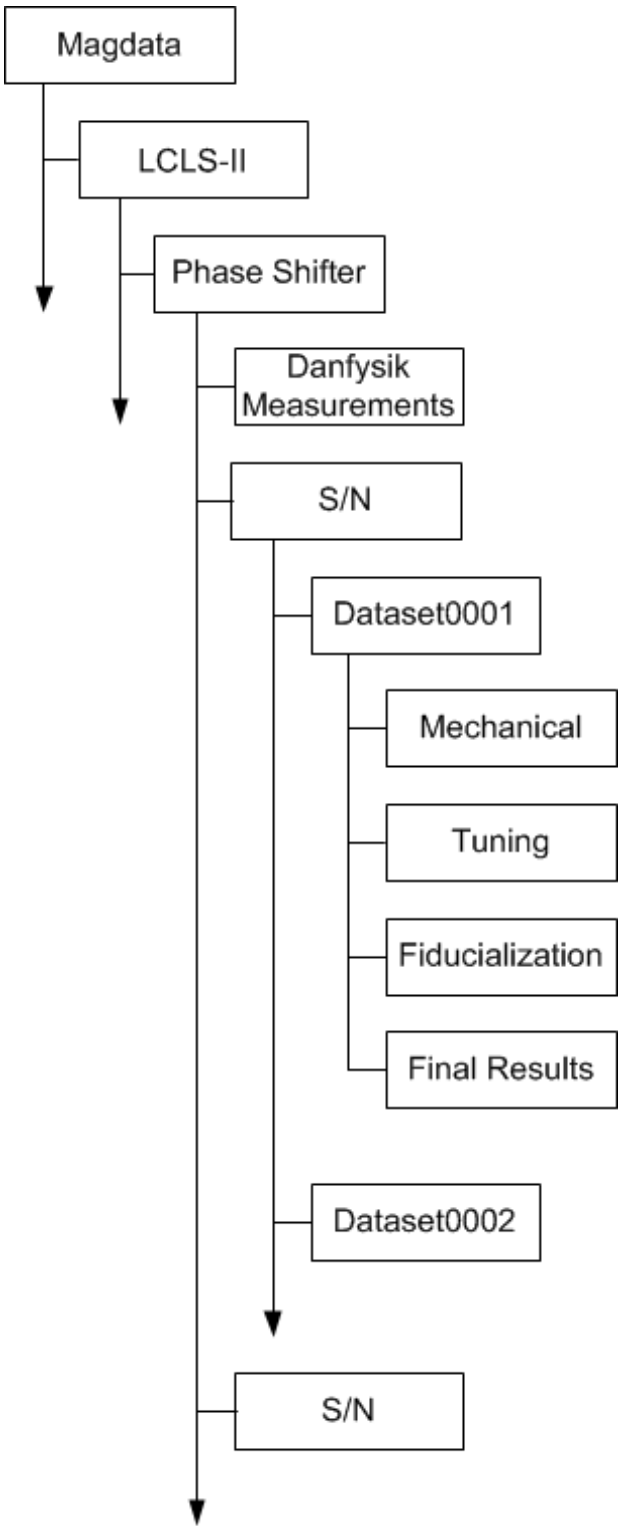

Figure 1: The phase shifter measurement data will be stored in a directory structure.

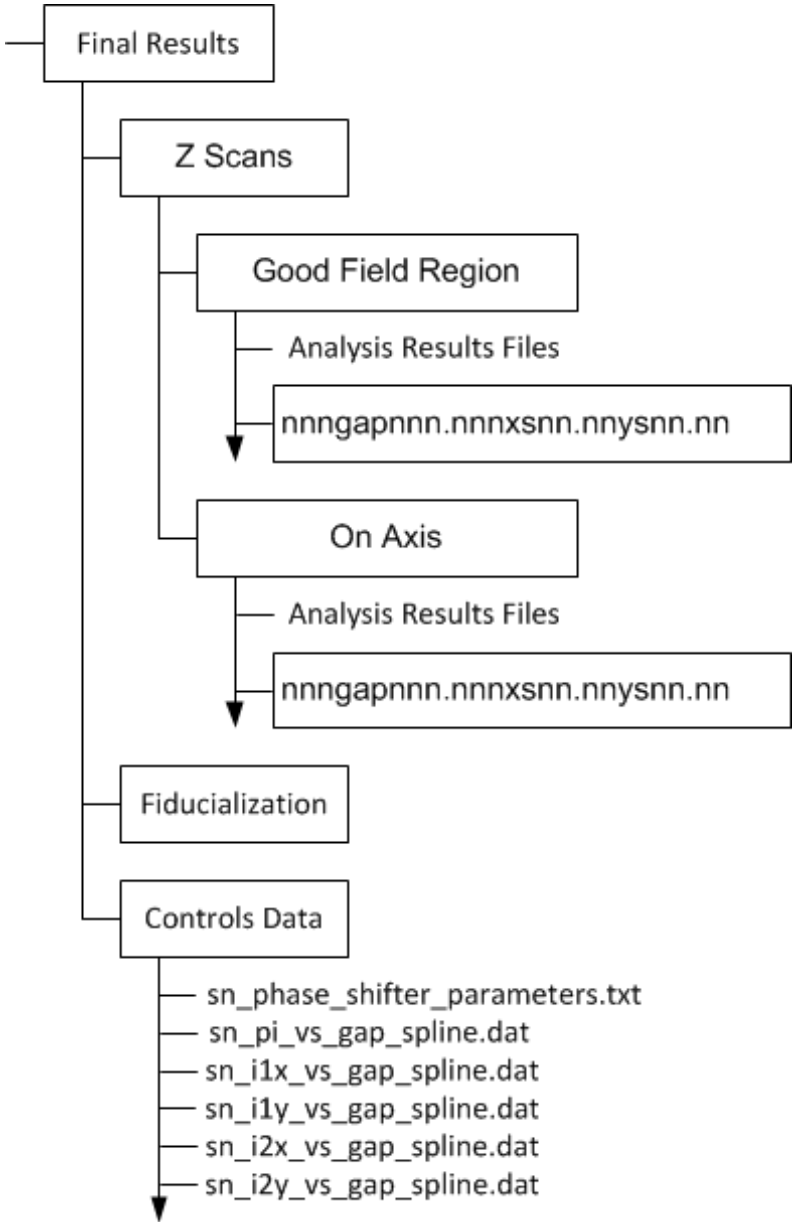

Figure 2: Contents of the Final Results folder.