LCLS-II-HE Phase Shifter Mechanical Test Plan

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Abstract

The phase shifters for LCLS-II-HE will use the same mechanical structure as the LCLS-II SXR phase shifters. New magnet arrays, however, will produce stronger forces. A test plan is presented to study the behavior of the mechanical structure under the increased loads.

1 Introduction[1]

The LCLS-II soft x-ray line (SXR) uses 20 phase shifters and their structural parts will be reused for LCLS-II-HE (SXR-HE). New magnet arrays will be added to the mechanical assemblies. In addition, 9 new phase shifter mechanical assemblies will be purchased and the new magnet arrays will be added to them. The SXR-HE line will have a total of 29 phase shifters.

The magnet arrays for the SXR-HE phase shifters will be larger and produce stronger magnetic fields than in the SXR phase shifters. At the minimum gap of 10 mm, the magnetic force on an SXR-HE magnet array is calculated to be approximately 310 pounds, while for an SXR magnet array, the force was calculated to be approximately 216 pounds[2]. We wish to determine whether the mechanical structure of the SXR phase shifters can operate properly with the larger forces of the SXR-HE magnet arrays.

At this point in the phase shifter design, we don't yet have an SXR-HE magnet array. We can simulate the increased forces, however, by reducing the gap on an SXR phase shifter. In this note, a plan is presented to reduce the gap of an SXR phase shifter so that the forces are the same as the SXR-HE forces. The behavior of the mechanical structure can then be studied under the increased loads.

2 Test Plan Objectives

The tests in this plan are meant to address the following questions. With the stronger forces:

1. Is the drive system capable of changing the gap at the required speed?

[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, "A Phase Shifter Design For LCLS-II-HE", LCLS-TN-21-2, January, 2021.

2. Can the gap be set with the required accuracy?

3. Are all components operating within their specifications?

4. Are there any signs of lifetime reduction?

3 Requirements

The LCLS-II-HE phase shifter requirements come from a Physics Requirements Document[3] and a technical note[4]. The requirements related to the mechanical system are briefly summarized below.

1. The phase shifter gap must reach a minimum value of 10 mm where the calculated force on each magnet array is approximately 310 pounds.

2. The accuracy for setting the gap must be better than 8 microns if the error on setting the gap is the only error. When temperature errors, alignment errors, and calibration errors are also considered, the tolerance for setting the gap is smaller. A formal error analysis has not been performed, but for this note we distribute the errors equally among the four sources and require the accuracy for setting the gap to be 8 microns $\div \sqrt{4} = 4$ microns or better.

3. The phase shifter gap speed must be 3x faster than the undulator gap speed during an energy scan. The current undulator gap speed is 0.2 mm/s, so the phase shifter gap speed must be at least 0.6 mm/s.

4 Test Plan

The steps in this plan are to be carried out using an SXR phase shifter. The gap is reduced below the normal operating limits in order to simulate the SXR-HE magnetic forces. A plot of calculated force vs gap is shown in figure 1.

Temperature will play an important role in the CMM measurements below. For instance, the motor will get hotter as it runs, and the aluminum strongback and stainless steel guide rail for the slides form a bimetallic assembly that can change shape with temperature. For all the CMM and capacitive sensor measurements below, also record the temperature of the motor, the strongback, and the phase shifter jaws. The tests for this plan are as follows:

1. Make a mechanical simulation of the phase shifter.

   (a) Determine deflections as a function of applied magnetic force.

   (b) Determine the required motor torque as a function of applied magnetic force.

[3] D. Cesar et al., "LCLS-II-HE SXR Undulator System", LCLS-II-HE Physics Requirements Document LCLSII-HE-1.3-PR-0049-R0, August, 2020.

[4] Z. Wolf, "A Phase Shifter Design For LCLS-II-HE", LCLS-TN-21-2, January, 2021.

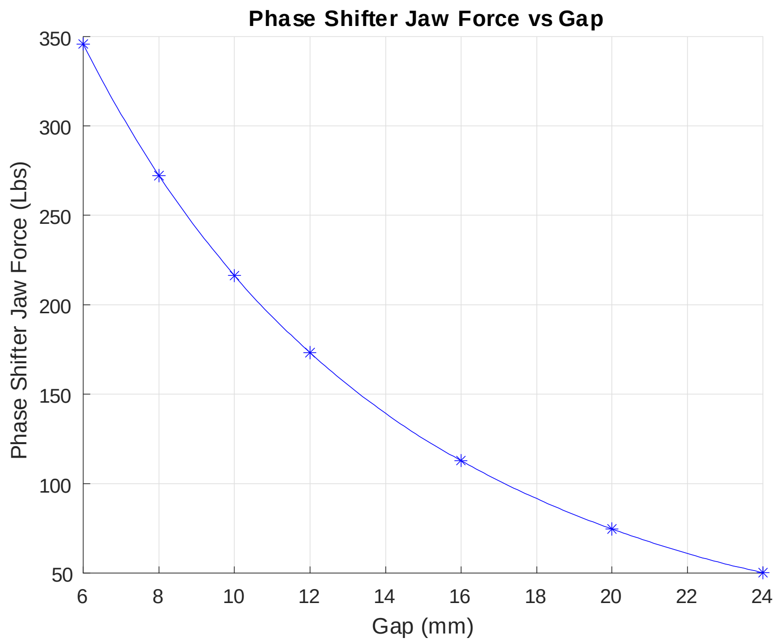

Figure 1: Calculated force as a function of gap for an SXR phase shifter.

   (c) Determine the required motor power when the phase shifter is operated at maximum force and maximum gap speed.
   (d) Determine the moments on the slides guiding the jaws.
   (e) Verify that all components are operating within their specifications.

2. Place the phase shifter on the CMM. Open the gap to 100 mm. Measure the jaw positions and strongback straightness. This determines a baseline for deflections.

3. Close the phase shifter gap to 7.0 mm. Measure the jaw positions and strongback straightness. Compare to the measurements when the gap was 100 mm and determine deflections. Compare to the model of the phase shifter. Verify that the deflections are consistent with a magnetic force of 310 pounds applied to each jaw.

4. Run the phase shifter from 7.0 mm to 8.0 mm at 0.6 mm/s.

   (a) Verify that the phase shifter can run at the required speed with the increased forces.
   (b) Measure the motor current. Verify that it is in the specified operating range of the motor.

5. Measure the gap repeatability.

   (a) Using the CMM, measure the gap when it is set to 7.0 mm.

(b) Open the gap to 7.5 mm, 8.0 mm, 8.5 mm, 9.0 mm, 9.5 mm, and 10.0 mm. Measure the gap using the CMM at each gap setting.

(c) Open the gap to 35 mm.

(d) Close the gap to 10.0 mm, 9.5 mm, 9.0 mm, 8.5 mm, 8.0 mm, 7.5 mm, and 7.0 mm. Measure the gap using the CMM at each gap setting.

(e) Repeat 5 times.

(f) Verify that the gap repeats to 4 microns at each gap setting value.

6. Perform a lifetime test.

   (a) Place capacitive sensors in the gap to measure the gap at 7.0 mm.

   (b) Write a program to set the gap to the following values in a cycle: 7 mm to 10 mm in 0.5 mm steps, 10 mm to 35 mm in 1 mm steps, 35 mm to 10 mm in 1 mm steps, 10 mm to 7 mm in 0.5 mm steps, 7 mm to 100 mm to 7 mm.

   (c) Run the program for 500 cycles and each time the gap is at 7 mm, record the capacitive sensor readings.

   (d) Verify that the phase shifter operates properly during and after this test.

   (e) Verify that the capacitive sensor measurements at 7 mm gap are repeatable to 4 microns for the duration of the test.

   (f) Verify that the motor temperature stayed within its specifications.

   (g) Using the CMM, verify that after the test the jaw positions and strongback straightness are the same as at the beginning of the test.

5 Further Studies

5.1 Smaller Gaps

The above test plan is for forces using the minimum 10 mm gap of an SXR-HE phase shifter according to the PRD. It may be possible, however, to operate the phase shifter at smaller gaps since the beam pipe through the phase shifter is nominally 6 mm high. Figure 2 shows the calculated SXR-HE phase shifter force on a jaw at small gaps. At 9 mm gap, the force on a jaw is approximately 340 pounds. If the SXR phase shifter gap is reduced to 6 mm, the force on a jaw is approximately 345 pounds. It may be possible to repeat the test plan using 6 mm as the minimum gap, but a study of measurement probe clearance must be made.

5.2 Magnetic Measurements

Passing the tests in the mechanical test plan of this note is necessary for using the SXR phase shifter mechanical structure for SXR-HE. In the end, however, the magnetic performance of the phase shifter is of utmost importance. After successful completion of the mechanical tests, a set of magnetic measurements should be made to verify the repeatability of setting the phase integral and to verify that there is small hysteresis in the phase integral when setting the gap from different directions.

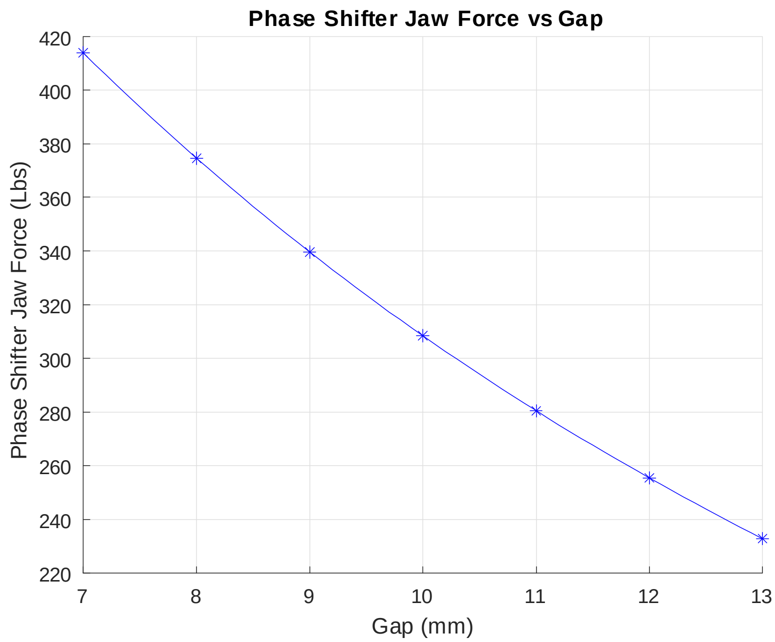

Figure 2: Calculated force on an SXR-HE phase shifter jaw at small gaps.

6 Conclusion

The tests described in this note are meant to verify that the SXR phase shifter mechanical system can operate properly under the increased SXR-HE magnetic forces. If all the tests are completed successfully, the SXR phase shifter mechanical structure can likely be used as-is. If any test is failed, design changes (for example, adding a force compensating spring) should be made and the test repeated. Once the mechanical test is successfully completed, magnetic measurements should be made to verify that the phase integral can be set repeatedly and without hysteresis.