MAGNETIC FIELD MEASUREMENTS AT LBNL ON SOFT X-RAY AND HARD X-RAY UNDULATOR SEGMENTS FOR THE LINEAR COHERENT LIGHT SOURCE UPGRADE (LCLS-II) PROJECT

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Abstract

Stanford Linear Accelerator Laboratory is currently constructing the Linear Coherent Light Source II (LCLS-II), a FEL which will deliver x-rays at an energy range 0.2-5 keV at high repetition rate of up to 1 MHz using a new 4 GeV superconducting linac, and at an energy range 1-25 keV when using the existing copper linac at up to 120 Hz. To cover the full photon energy range, LCLS-II includes two variable-gap hybrid-type permanent magnet undulator lines: A soft x-ray undulator (SXR) line with 21 undulator segments for the photon energy range 0.2-1.3 keV plus a hard x-ray undulator (HXR) line with 32 undulator segments designed for a photon energy range from 1-5 keV when using the superconducting linac. The HXR line is also designed to support 25 keV and higher photon energies when using the existing copper linac. Lawrence Berkeley National Laboratory (LBNL) is responsible for fabricating the undulators and tuning 23 of the HXR undulators. This paper summarizes the magnetic field measurements carried out on the pre-production undulators and describes the plans at LBNL for the magnetic measurements on the HXR undulators in series production.

INTRODUCTION

Lawrence Berkeley National Laboratory (LBNL) is presently manufacturing 32 hard x-ray and 21 soft x-ray undulator segments for two variable-gap, hybrid type permanent magnet undulator lines to be installed at the Linear Coherent Light Source II (LCLS-II) project [1] at Stanford Linear Accelerator Laboratory (SLAC). The main parameters and magnetic and mechanical design features of the LCLS-II undulators of the type SXR and HXR are described in [2]. Both the SXR and HXR are 3.4 m long variable gap undulator with a minimum operational gap of 7.2 mm. The SXR undulators have a vertical magnetic field with the period length 39 mm and the HXR undulators have a horizontal magnetic field with the period length 26 mm.

The in total 53 HXR and SXR undulators will be produced and tuned during a time span of approximately 2 years. The undulators will be transported with road transport to SLAC after assembly and tuning, where they will be measured and tuned again and then stored before installation in the LCLS-II tunnel. A series of environmental tests and magnetic measurements has been carried out in order to verify that the performance of the undulators is not deteriorated by the environmental challenges of temperature changes of ±15°C from the average 20°C in the storage room and the road transport with truck to SLAC. All magnetic measurements have been carried out in the Undulator Measurement Facility (UMF) at LBNL, which is equipped with a 6.5 m long Hall probe bench and a flip coil that is aligned to the Hall probe bench. The UMF is temperature controlled to have a stable temperature of 20±0.1°C.

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ENVIRONMENTAL TESTS

The environmental tests were carried out on a prototype undulator called HXU-32, which in most aspects is identical to the vertical field SXR undulator but the period length is 32 mm instead of 39 mm.

Heating of Undulator

The heating test was carried out in September 2015 by installing an insulated enclosure around the HXU-32 undulator as shown in Figure 1 and use electrical heaters inside the enclosure to rise the temperature.

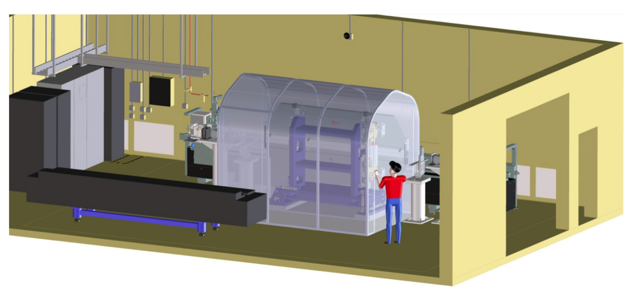

Figure 1: Insulated enclosure around the HXU-32 undulator used for the heating and cooling of the undulator during the environmental tests in the UMF.

The complete undulator was heated up to a temperature of 35°C or higher, which took approximately 12 h. The magnetic fields were measured and analyzed before and after the heating test. The heating did not affect the phase error values but a small decrease in the effective field was observed, see Table 1, together with a moderate change of the field integrals. It could not be determined if the change in effective field was depending on a change of the properties of the magnet material or a mechanical change of the gap encoder. The HXU-32 undulator stayed within the specifications over the heating test, except for the variation of the effective field which also may depend on a mechanical

Table 1: Measured Effective Magnetic Fields B_{eff} Before and After the Temperature Variation and Transport Tests. B_{effA} is the average effective field from a Fourier analysis of a cycle spanning 80 measurements. B_{effS} is the effective field calculated from the trajectory at a single measurement.

	Before heating		After heating	
Gap mm	B_{effA} T	B_{effS} T	B_{effA} T	B_{effS} T
7.2	1.2831	1.2863	1.2828	1.2856
8	1.1594	1.1615	1.1590	1.1611
10	0.90420	0.90585	0.90402	0.90570
15	0.51764	0.51872	0.51756	0.51863
20	0.30890	0.30976	0.30887	0.30968
	Before cooling		After cooling	
Gap mm	B_{effA} T	B_{effS} T	B_{effA} T	B_{effS} T
7.2	1.2801	1.2825	1.2798	1.2822
8	1.1572	1.1591	1.1569	1.1587
10	0.90355	0.90514	0.90340	0.90493
15	0.51797	0.51901	0.51787	0.51893
20	0.30913	0.30996	0.30907	0.30989
	Before transport		After transport	
Gap mm	B_{effA} T	B_{effS} T	B_{effA} T	B_{effS} T
7.2	1.2800	1.2821	1.2806	1.2826
8	1.1571	1.1589	1.1576	1.1591
10	0.90363	0.90512	0.90381	0.90512
15	0.51804	0.51895	0.51810	0.51892
20	0.30921	0.30989	0.30927	0.30991

deformation of the gap encoder system. The gap encoder system was later modified for the SXR undulators.

Cooling of Undulator

The cooling test was carried out in October 2015 using the insulated enclosure and a high power mobile cooling unit to lower the temperature. The cooling of the undulator took several days and the highest temperature on the complete undulator was 8°C at the end of the cooling cycle.

The cooling did not affect the phase error values but a small decrease in the effective field was observed, see Table 1, together with a small change of the field integrals. The HXU-32 undulator stayed within the specifications over the heating test, except for the variation of the effective field which as for the heating test may depend on a mechanical deformation of the gap encoder system.

Transport of Undulator

The transport test was carried out in January 2016. The HXU-32 undulator was transported on a truck from LBNL to SLAC and back to LBNL again for magnetic measurements. The transport did not affect the phase error values and only small changes of the field integrals were observed for the central part of the undulator. The effective field was increased by the transport test, see Table 1. The gap repeatability was affected by the transport test and it was discovered that corrosion had appeared in the contact point between the ball bearing ball and contact plate for the gap encoder system due to fretting during the transport. A conclusion from the transport test was that the encoder heads must be secured with a damping material during transports to avoid wear at the contact point for the encoder.

TUNING AND MEASUREMENTS OF THE SXR UNDULATOR

The first SXR undulator, a pre-production unit, was assembled and tuned during 2016. The initial experience during the assembly and tuning was that it is very important to keep a uniform distance between magnets and poles along the undulator. After a uniform distance between magnets and poles had been obtained the tuning converged rapidly using the tuning methods and tuning software developed for the SXR undulators. All requirements were met for the SXR undulator. The maximum effective field requirement was met at the gap 7.7 mm, which is larger than the required minimum gap of 7.2 mm.

The gap encoder system that had been modified following the experience from the environmental tests with the HXU-32 undulator showed to work well. Figure 2 shows the gap repeatability measurements after tuning.

Figure 3 shows the second field integral of the SXR undulator along the undulator. Figure 4 shows the phase error distribution along the poles of the SXR undulator.

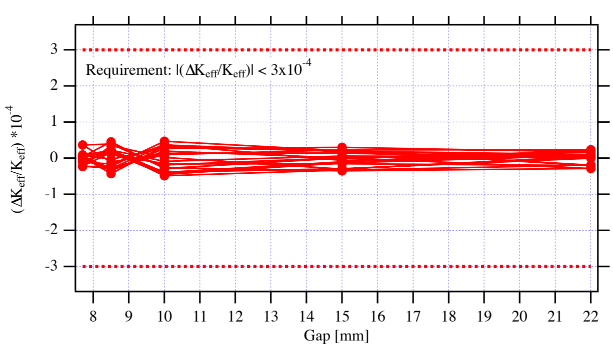

Figure 2: The measured deviation of the effective field at the repeatability measurements as a function of the gap over 10 gap-cyclings over the gap range 7.7 to 22 mm.

PLANNED MEASUREMENTS AND TUNING OF HXR UNDULATORS

The first pre-production unit of the HXR undulators was assembled in March 2017 and it was ready for the initial magnetic field measurements in April 2017. The initial measurements on the HXR undulator show that the field integrals, trajectory errors, and phase errors are moderate and comparable to the specifications already at the initial measurement. The assembly of the undulator and sorting of the magnets have hence work satisfactory. At present, May 2017, the tuning signatures of the tuning methods are measured and the software for carrying out the tuning is

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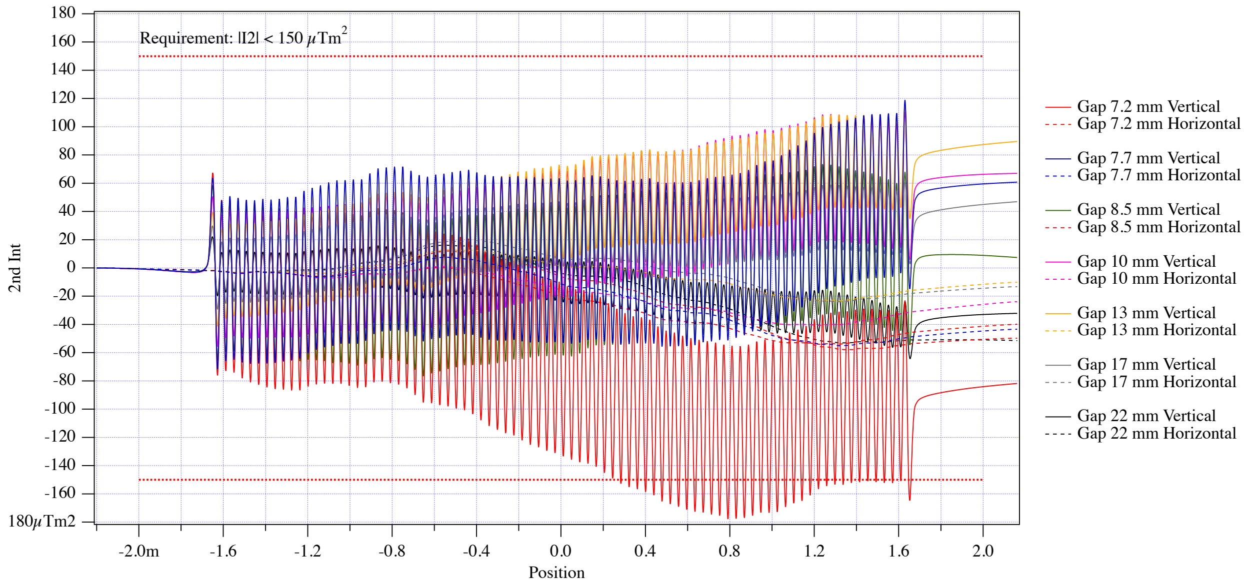

Figure 3: Second field integral of the SXR undulator along the undulator at the gaps 7.2, 7.7, 8.5, 10, 13, 17, and 22 mm.

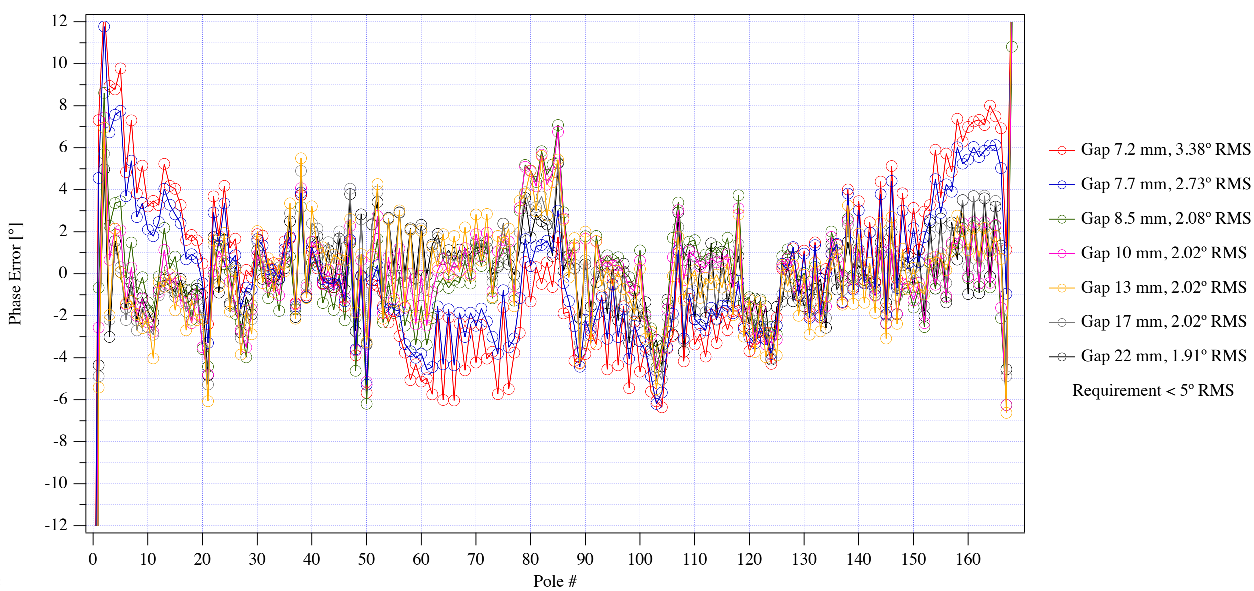

Figure 4: Phase error distribution along the poles of the SXR undulator at the gaps 7.2, 7.7, 8.5, 10, 13, 17, and 22 mm..

being calibrated to facilitate a rapid tuning once the series production of undulators starts in the late summer of 2017. In total 23 HXR undulators will be tuned at LBNL. The foreseen time it takes to tune one HXR undulator is maximum two weeks, including installation, alignment, measurements and removal from the UMF.

ACKNOWLEDGMENTS

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