LCLS Physics Specifications for the SXRSS Beam Overlap Diagnostics

LCLS Physics Requirements Document

Document Approval (signature/date)

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1 Purpose

The SXRSS Beam Overlap Diagnostics PRD provides the physics requirements for the overlap diagnostics as part of the SXRSS project for the LCLS undulator.

2 Scope

This document covers the overlap diagnostics to be installed after girders 9 and 12 of the LCLS undulators.

3 Definitions

SXRSS	Soft X-Ray Self Seeding
BLM	Beam Loss Monitor
BFW	Beam Finder Wire
MPS	Machine Protection System

4 References

SLAC-I-030-601-002-00	SXRSS Beam Overlap Diagnostics ESD
SLAC-I-030-601-002-00	SXRSS Conceptual Design Report

5 Responsibilities

N/A

6 Overview

The SXRSS project replaces the LCLS undulator segment 9 with a 4-magnet chicane and a grating monochromator to enable self-seeding capability for soft x-rays at LCLS. Both the electron beam via the chicane and the x-ray seeding beam via the grating and mirrors can get displaced from their original path through the downstream undulators. Optimal performance of the self-seeding requires that both beams overlap for one gain length (~3 m) downstream of the chicane system within a small fraction (~5 µm) of their beam sizes (~30 µm) and that both beams resume the original trajectory for normal SASE operation. Although the absolute electron beam orbit can easily be recovered to µm accuracy with the existing BPM system and the optimum relative overlap of both beams can be achieved by maximizing the FEL output at the seed wavelength, initial commissioning requires a diagnostics to set and verify the relative overlap to 10 µm accuracy to ensure a detectable signal of the seeded FEL.

The existing undulator layout makes it feasible to add an overlap diagnostic device to each of the two long break sections between undulators 9 & 10 and 12 & 13, respectively. This more than satisfies the one gain length overlap requirement. A schematic of the SXRSS chicane and overlap diagnostics is shown in Fig. 1.

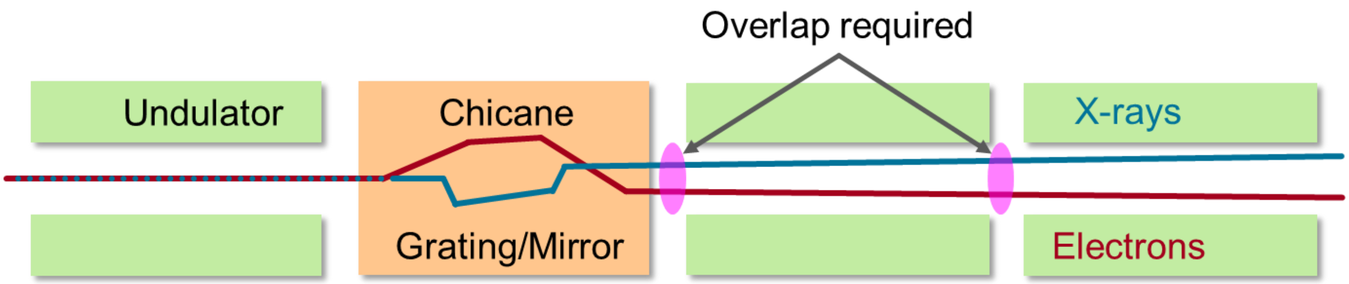

Figure 1: Schematic of the SXRSS setup and the paths of electron and x-ray beams.

6.1 General Requirements

The overlap diagnostics shall consist of a combination device capable of detecting the electron beam and the x-ray beam position, and capable of referencing both position measurements relative to each other. Electron and photon beam properties, and specifications for the main diagnostic elements are given in Table 1.

Table 1. Physics specifications for SXRSS beam overlap diagnostics

Parameter	**Nominal value**	**Units**
Electron beam energy	3.35 – 4.74	GeV
Photon energy	500 – 1000	eV
Seed pulse energy	1	nJ
Diagnostics location	9 & 12	
Electron beam size	40	µm
X-ray beam size @ U9	40 – 50	µm
X-ray beam size @ U12	170 – 500	µm
YAG size	10 x 10	mm
YAG thickness	20	µm
Wire material	Carbon	
Wire diameter	40	µm
Beam stay clear requirement	8	mm

The electron beam position measurement will use a system similar to the existing undulator BFW system by providing two insertible crossed wires which will be moved through the electron beam by moving the supporting girder of the downstream undulator and by detecting the resulting beam loss with the existing undulator BLMs.

The x-ray FWHM beam sizes at both diagnostics locations are expected to be between 40 – 50 µm at the girder 9 location and between 170 – 500 µm at girder 12, depending on the x-ray photon energy.

The x-ray beam position will be measured with a YAG screen similar to existing x-ray diagnostics. The x-ray seed pulse energy *E* through the monochromator is estimated at 1 nJ (20 kW x-ray power and 50 fs pulse duration). The YAG fluorescence efficiency η is 18,000 ph/MeV, the lens acceptance θ is assumed to be 100 mrad, the CCD quantum efficiency *QE* as 50%, and the ADC digitizing (*ADC*) at 0.25 counts/e^-. The total number of CCD counts can then be estimated as $N_{Counts} = E\ \eta\ \sin^2(\theta/2)\ QE\ ADC = 40{,}000$.

The x-ray beam sizes σ are around 50 to 500 µm according to Table 1. For an effective pixel size (virtual pixel size in the object, lens magnification taken into account) *d* of 10 µm and a ADC readout noise N_{Noise} of 4 counts, the signal to noise ratio can be determined to $S/N = N_{Counts}/N_{Noise}\ (d/\sigma)^2 = 400$ for the 50 µm upstream beam size. The signa to noise ratio for integrated beam profiles used to determine the beam centroid position is then $S/N = N_{Counts}/N_{Noise}\ (d/\sigma)^{3/2} = 900$ which includes the fact that the readout noise decreases with the square root of the number of integrated pixels. Considering the same pixel size at the larger downstream beam sizes, the *S*/*N* ratio decreases to 8, and for the profiles to 40 – 50. However, the overlap accuracy is given as a fraction of the beam size, and the 5 – 10 times larger beam size at the downstream location means the accuracy can be relaxed to 50 – 100 µm with correspondingly larger pixel sizes and the same *S*/*N* ratio as for the small beam size.

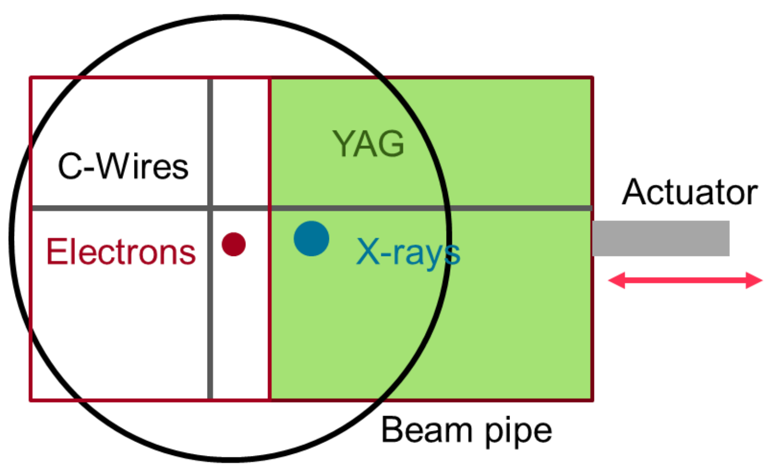

Figure 2: Schematic of overlap diagnostics with YAG crystal and wires.

The relative position between the wires and the x-ray location on the YAG screen can be obtained through CCD observation of both the YAG fluorescence and the illuminated wires by locating the screen and the crossed wires in close proximity to each other and within the same z-location. The arrangement of both wires and YAG crystal is shown in Fig. 2

6.2 YAG Crystal

The x-ray absorption occurs within a thin surface layer on the front of the crystal and therefore the crystal should be as thin as possible to minimize radiation exposure of the undulators from an accidental hit by the electron beam, while still mechanically stable. A feasible range is 20 to 50 µm thickness, the preliminary approval by SLAC Radiation Physics specifies 20 µm. The crystal size shall be 10x10 mm square to be able to cover the visible area as exposed from the 8 mm upstream beam pipe apertures. The crystal shall be oriented perpendicularly to the beam axis with its vertical edge separated by 2 mm from the adjacent crossed wire intersection point and as close as possible in the same plane as the wires.

6.3 Wires

The two wires shall be made of carbon and of 40 µm diameter to minimize radiation exposure. They shall be oriented vertically and horizontally, respectively, and mounted on the same common holder as the YAG crystal with the YAG crystal located closest to the far end of the actuator.

The wire crossing location shall be shifted by 0.5 mm vertically and horizontally from the beam axis in the nominal actuator position such that this leaves 1.5 mm between the nominal beam position and the YAG edge. The beam position measurement will utilize the ±1 mm girder motion range to move the wires.

6.4 Optical

The working distance and f/# of the lens shall be as short as possible to maximize numerical aperture and light collection. A working distance of 140 to 200 mm and f/# lesser than 3 is compatible with the presently used lens in the LCLS accelerator cameras.

The effective pixel size shall be 10 µm with an optical resolution of better than 20 µm to achieve the position resolution requirement.

A mirror shall be placed in front of the YAG/wire assembly at 45 degrees to enable viewing of the diagnostics through a viewport above the mirror. An annulus of at least 8 mm diameter in the mirror coaxial to the beam line axis shall provide the necessary beam stay clear. The inner diameter of the reflective surface shall not be smaller than 12 mm. The outer projected mirror diameter shall be at least twice the inner diameter of the reflective mirror surface to limit the light collection loss from the annulus to less than 25%. Both the mirror substrate material and the surface material shall be aluminum. The surface quality figures shall be lambda/5 flatness and 40-60 scratch-dig.

No mechanical aperture other than the annulus in the mirror shall obstruct the clear sight of the full extent of the YAG screen from the lens.

The support structure for the camera and lens shall have 3° pitch and yaw adjustment range and it shall be possible to set the roll of the camera support during installation. A coarse setting of the camera vertical position within the above stated range of working distance shall be provided. The camera alignment shall be maintained during camera replacement. The camera horizontal axis shall not be clocked w.r.t. the horizontal electron beam axis other than 0° or 180°.

A remotely controlled illumination through a second window close to the YAG/wire assembly shall provide necessary visibility of the wires for the CCD.

6.5 Mechanical

The actuator to move the YAG/wire assembly shall move in the horizontal direction to utilize the additional steering capability in the horizontal plane from the chicane trim coils.

The alignment tolerances for the wires, YAG and mirror are given in Table 2. The degrees of freedom are given with respect to the beam line coordinates.

Table 2. Alignment tolerances for SXRSS beam overlap diagnostics, degrees of freedom are given relative to beam line coordinates, (pitch, yaw, roll) are rotations about (x, y, z)

Parameter	DOF	Value	Units
Target position reproducibility	z	100	µm
	x,y	10	µm
	pitch	20	mrad
Actuator motion axis accuracy	roll,yaw	10	mrad
YAG to wire cross relative position accuracy	z	50	µm
	x	100	µm
Wire perpendicularity		10	mrad
Wire cross position accuracy	x,y,z	100	µm
	pitch,yaw	20	mrad
	roll	10	mrad
YAG crystal position accuracy	y	500	µm
	x	100	µm
	pitch,yaw	20	mrad
	roll	20	mrad
Annular mirror position accuracy	x,y	100	µm
	z	1	mm
	roll,pitch, yaw	20	mrad

The holder for the YAG/wire (“wire card”) shall have clearances matching the 8 mm stay clear in both the “retracted” (fail save) and “inserted” position. The “inserted” position shall have enough clearance to position the vertical wire up to two mm horizontally off center and to fully insert the YAG crystal. Limit switches shall indicate mechanical travel limits for the actuator as well as clearance positions for MPS.

Revision History

Revision	Date Released	Description of Change
R000		Original Release.