Stanford Linear Accelerator Center
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LCLS Physics Requirements Document # 1.5-004	X-Ray Transport and Diagnostics	Revision 0

Physics Requirements for the XTOD Soft X-Ray Offset Mirror System

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Brief Summary

This document provides general physics requirements for the XTOD Soft X-Ray Offset Mirror System (SOMS), an optical system designed to substantially reduce the levels of high-energy spontaneous radiation, Bremsstrahlung γ-rays and their secondary radiations within the LCLS Experimental Halls. At the same time, this System strives to minimally degrade the intrinsic characteristics of the LCLS FEL beam.

Change History Log

Rev Number	Revision Date	Sections Affected	Description of Change
000	2006/11/1	All	Initial Version

1. Introduction

The XTOD Offset Mirror Systems are designed to spatially separate the useful FEL radiation from high-energy spontaneous radiation and Bremsstrahlung γ-rays. These unwanted radiations are generated in the LCLS undulator and in nearly 400 meters of straight electron beam transport upstream of the Electron Beam Dump. While the FEL radiation is specularly reflected by the Systems, most of this other radiation is absorbed-on or interacts-with specific components and shielding collimators located in the Front End Enclosure (FEE). The resulting secondary radiations are then absorbed in the FEE perimeter shielding. As a result, levels of these unwanted, background radiations can be substantially reduced within the downstream LCLS Experimental Halls and beam transport areas.

The Systems basically generate 2 branch beam lines, a soft x-ray line and a hard x-ray line, from the initial, incident beam. Each branch line consists of at least one mirror pair and 4 collimator shields. As illustrated in the example pictorial layouts below, the Hard X-Ray Offset Mirror System (HOMS) offsets the beam vertically, parallel to the incident beam. The Soft X-Ray Offset Mirror System (SOMS) deflects the beam horizontally. In either case, under normal operating conditions, the high-energy spontaneous radiation and Bremsstrahlung γ-rays penetrate the first mirror of a mirror pair, since these radiations exceed the mirror cut-off for reflection. While some of this radiation scatters from the first mirror, the arrangement of subsequent shielding collimators in the Systems precludes any line-of-sight passage of this scattered radiation downstream. Only one System/branch line can be active at a time. The HOMS and SOMS will be interdigitated, and one mirror must be extractable from the beam, to switch from one System to the other. Both Systems use Collimator C1.

This document sets requirements for the SOMS. Requirements for the HOMS are discussed in a separate Physics Requirements Document (PRD).

The SOMS strives to minimally degrade the intrinsic characteristics of the LCLS FEL beam. The requirements on the mirror optical elements (as opposed to system requirements, like stability) balance desired performance with currently-achievable fabrication results. For example, the mirrors should ideally preserve the FEL beam divergence, without broadening. However, at the highest photon energies, this requirement translates into a figure specification that is likely beyond the current state-of-the-art capabilities of vendors.

In the end, therefore, the **first** sets of mirrors used in the Offset Mirror Systems are unlikely to be the **last**. As experimental requirements mature and evolve, and technology is tested and responds to the challenge, more-capable mirrors will appear. For now, the specification process adopted here is hoped to be a good first step, and should enable the first-generation of LCLS experiments.

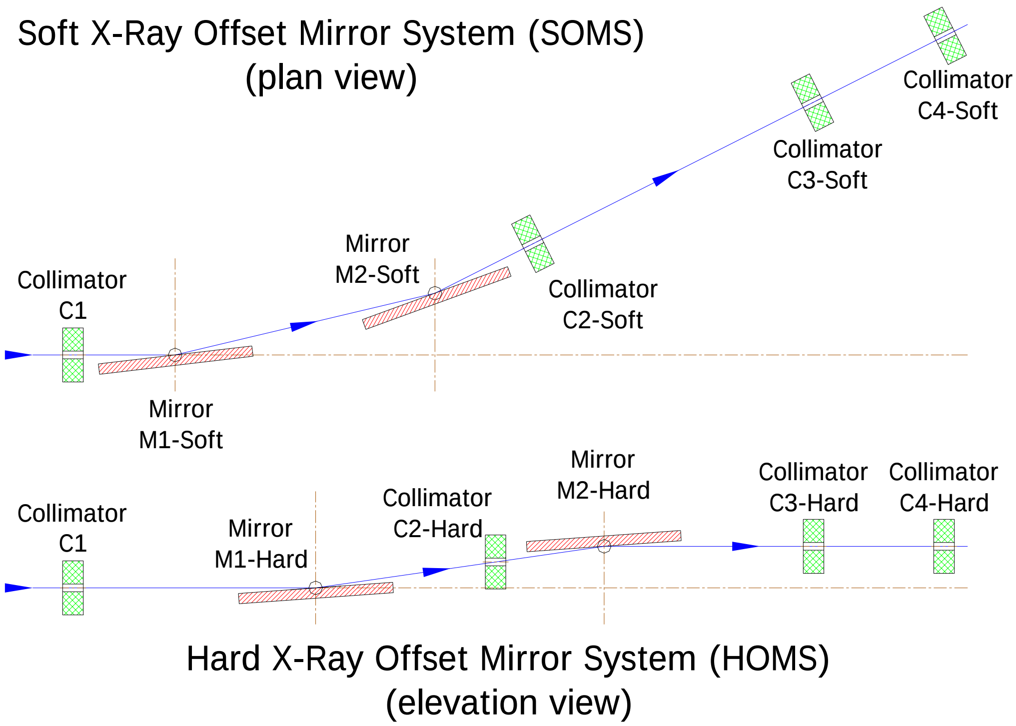

Figure 1: Example configurations for the Offset Mirror Systems

2. Fundamental Requirements

2.1. Photon Energy Range: The SOMS shall operate in the FEL photon energy range from 826.5 eV to 2000 eV. (This implies a grazing-incidence angle of approximately 15 mrad for mirrors with sputtered B_4C reflecting surfaces on silicon substrates.)

2.2. Mirror System Configuration: A functional, detailed layout of the SOMS will be proposed by XTOD and analyzed for effectiveness by SLAC Radiation Physics. Through mutual negotiation, the final configuration will be determined.

2.3. Mirror System Acceptance: The SOMS shall consist of optical elements sized to accept at least 95% of the FEL radiation cone. (This corresponds to capturing the central 5.0σ width of a beam with a 2D Gaussian profile). Since the transverse dimension of the FEL beam increases with decreasing FEL photon energy, the length of each optical element is set by the lowest photon energy to be reflected: 826.5 eV for the SOMS.

2.4. Protection of Mirror Substrates: Due to the grazing-incidence geometry of the SOMS mirrors, an upstream face of each mirror substrate will be oriented at near-normal incidence to the direct FEL beam. To prevent any potential damage from such direct illumination of the substrate by the FEL, instrumented, FEL-proof shields (e.g. a 10 mm thick plate of B_4C) shall be incorporated in each mirror holder to protect this upstream face of the mirror substrates.

2.5. Mirror Pointing Stability: As implied by PRD 1.5-001, *Physics Requirements for the LCLS X-Ray Transport and Diagnostics,* the pointing stability of the SOMS shall limit output beam position motion to less than 10% of the beam size (FWHM). This is interpreted to apply to short-term, long-term and shot-to-shot beam motion, and therefore places design requirements on system mechanical stability, either static, or through position-feedback systems, and on system mechanical rigidity and vibration modes (PRD 1.5-002, *Physics Requirements for the XTOD Mechanical-Vacuum Systems*, section 4).

2.6. Mirror Reflectivity: Also implied by PRD 1.5-001, the total reflectivity of the SOMS should be kept high. Therefore, the reflectivity of each mirror in the SOMS shall exceed 90% over its required photon energy range.

3. Optical Requirements

3.1. Basic Mirror Geometry: The SOMS mirrors shall have flat, planar reflecting surfaces, with minimum tangential radii in the tens-of-kilometer range.

3.2. Mirror Surface Specifications: Mirror surface specifications (conventionally described as “figure” and “micro-roughness” or “finish”) shall be designed to limit degradation of FEL divergence and transverse coherence. The effect of a given, characterized mirror surface can be readily predicted as it impacts FEL divergence degradation, and this has been utilized in the derivation of the requirements which follow. However, prediction of transverse coherence degradation is more problematic.

The transition from a geometric optics regime (one dominated by figure errors, with no dependence on wavelength) to a diffraction regime (where the scattering is wavelength-dependent) depends on the mirror configuration and the incident beam. Numerical simulations for the XTOD Offset Mirror Systems show that **both** regimes have significant effect on the FEL beam. It is of utmost importance, then, that all surface specifications include a spatial-frequency/roughness-wavelength range.

We define three mirror specifications, based on the spatial frequency domain of their errors: low-spatial frequency (Figure, slope errors), mid-spatial frequency (Mid-Spatial Roughness), and high-spatial frequency (High-Spatial Roughness). The table below summarizes the specification name, spatial frequency range (and the equivalent roughness wavelength range), and the specification value. In all cases, the numerical specification value is obtained as an rms average over the corresponding frequency range specified. Moreover, the spatial frequency range for the High-Spatial Roughness corresponds to those frequencies conventionally accessible by performing Atomic Force Microscope (AFM) measurements over 2×2 μm^2 and 10×10 μm^2 regions. For the Figure measurement, the metrology shall be performed with a laser interferometer or long-trace profilometer, and the specification value is to be determined from the rms slope errors over length scales from the full dimensions of the optic down to 1 mm.

Error Category	Spatial Frequency Range	Roughness Wavelengths	Specification
High-Spatial Roughness	0.5 μm^{-1} to 50 μm^{-1}	20 nm to 2 μm	≤ 0.4 nm rms
Mid-Spatial Roughness	10^{-3} μm^{-1} to 0.5 μm^{-1}	2 μm to 1 mm	≤ 0.25 nm rms
Figure (slope errors)	(mirror size)$^{-1}$ to 10^{-3} μm^{-1}	mirror size to 1 mm	≤ 0.25 μrad rms

3.3. Mirror Materials Specifications:

3.3.1. Overall Materials Specification: The materials used for the mirrors shall be chosen to withstand long-term incidence of the fully-saturated FEL beam, with its accompanying spontaneous radiation and Bremsstrahlung γ-rays, without degradation. This naturally leads to a selection of low-Z materials, including Be, B_4C, C, Al_2O_3, Si, and SiC. The entire mirror can be fabricated out of a single material, or an appropriate coating of one material can be deposited on top of a mirror substrate consisting of a second material.

3.3.2. Reflective Material Specification: The material which reflects the FEL shall, in addition, have no absorption edges in the photon energy range of operation. This precludes the use of silicon, for example, for the reflective surface of the SOMS mirrors. In the event that a reflective coating is deposited on top of a substrate, this requirement then applies to the finished mirror (coating deposited on top of the substrate).

3.4. Harmonic Rejection in the SOMS: The high-photon-energy cut-off of the SOMS is chosen to provide third harmonic rejection from the 826.5 eV FEL fundamental. To be effective, the System reflectivity at 2.48 keV must be below 20%.

4. Controls:

4.1. Remotely-Controllable Degrees-of-Freedom: Mirror movers for the SOMS shall permit mirror alignment in all six degrees-of-freedom. However, only two of these degrees need to be remotely-controllable, the rotation which controls the angle-of-incidence of the FEL beam on the mirror surface, and the translation perpendicular to the mirror reflecting surface, which serves to insert or retract the mirror from the FEL beam. Hand-operated controls for the other degrees-of-freedom should be acceptable.

4.2. MPS for Offset Mirror System Exchange: When the Offset Mirror System in use is exchanged for the other (e.g., the SOMS is exchanged for the HOMS), one mirror will be inserted or withdrawn, to send the FEL beam to the other System. The Machine Protection System (MPS) will be needed initially, to stop the FEL beam from entering the collection of Offset Mirror Systems until the mirror translation has been completed and the new System returns to a nominally-operational configuration.

5. Other Requirements

5.1. Vacuum Requirements for Mirror Enclosures: To maintain high-reflectivity mirror surfaces, and the desired high-photon-energy cut-off, the mirror surfaces must remain clean. This requires a vacuum level of ~ 1 x 10^{-10} Torr **at the mirror surfaces**. Therefore, “molecular beams” from instruments upstream or downstream must also be identified and eliminated.

5.2. Thermal Loading Considerations: Designs must be evaluated according to PRD 1.5-002 section 7. In this case, system stability might be compromised by even minor temperature fluctuations under beam-power loading.