ENGINEERING SPECIFICATION DOCUMENT (ESD)	Doc. No. SP-391-000-61 R0	LUSI SUB-SYSTEM X-Ray Optics

Engineering Specifications for the Harmonic Rejection Mirror System

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1. Overview

A two bounce offset mirror system will be used as a low pass filter to reject harmonics of the FEL fundamental. This document describes the engineering specifications of this system.

2. Applicable Documents, Specifications and Codes

2.1. Stanford Linear Accelerator Center (SLAC) Specifications

[01]	FP-202-631-14	Fabrication of UHV Components (includes further specifications e.g. SC-700-866-47 approved lubricants)
[02]	SP-391-000-33	Physics Requirements for the XPP Instrument
[03]	SP-391-000-34	Physics Specifications for the LUSI HRM System
[04]	DS-391-000-36	Mechanical Design Standards Supplement
[05]	SP-391-001-19	Engineering Specifications for the LUSI Common Instrument Control
[06]	SP-391-001-25	XCS - Controls - Interface Control Document
[07]	SP-391-001-35	Physics Requirements for the XCS Instrument
[08]	SP-391-001-45	XPP - Diagnostic and Common Optics - Interface Control Document
[09]	ID-391-300-01	XPP - Raft Assembly & Installation
[10]	AD-391-945-00	HRM Top Assembly
[11]	LCLS 1.1-014	LCLS Beam Parameters PRD
[12]	LCLS 1.9-113	XCS - Engineering Specification for Hutch 5 of the FEH
[13]	LCLS 1.9-1017	LCLS Room Data Sheet, Near Experimental Hall Overall
[14]	LCLS 1.9-1037	LCLS Room Data Sheet, Far Experimental Hall Overall

2.2. Acronyms

CF	Conflat Vacuum Flange
FEH	Far Experimental Hall
FEL	Free Electron Laser
FWHM	Full Width Half Max
HRM	Harmonic Rejection Mirrors
LCLS	Linac Coherent Light Source
LUSI	LCLS Ultrafast Science Instruments
NEH	Near Experimental Hall
PRD	Physics Requirement Document
XCS	X-Ray Correlation Spectroscopy
XPP	X-Ray Pump Probe

3. General Requirements

3.1. Location

- XPP: The HRM shall be mounted on a common support with the other optics in Hutch 3. They shall to be mounted downbeam of a LUSI Pulse Picker and upbeam of a LUSI Slit System.

- XCS: The HRM shall be mounted on a common support with the other optics in the upbeam segment of Hutch 4. They shall to be mounted downbeam of a LUSI Pulse Picker and upbeam of the Defining Slits.

3.2. Environment

The HRM shall be installed in a typical lab environment. The hutches shall be temperature controlled as specified [12]. The derived temperature and humidity values from this reference are:

- Temperature:
  For assigned purposes typically 72°F +/- 1°F [12]-[chapter 13.1]

- Humidity:
  For assigned purposes typical operating in 45 +/- 10% relative humidity [12]-[chapter 13.9]

- Vibration:
  The vibration environment is a function of how the facility generated vibrations are transmitted through the optics raft and the six degree of freedom mounting (Section 5.13) to the raft. In order to avoid interactions with lower frequency and higher

amplitude facility vibrations, the HRM chamber shall have a fundamental mode of vibration greater than 120 Hz.

- Radiation:
  HRM shall be capable of withstanding 1 Krads/year for its lifetime as defined in Section 3.4.

- HRM design shall incorporate covers to protect moving parts including bellows from airborne dust.

3.3. Maintenance, Accessibility and Operations

The downbeam mirror shall have the capability to deflect the beam parallel to the z-axis (normal mode of operation) or deflect the beam down again (high incidence angle mode). Breaking vacuum shall be acceptable when changing between these modes.

Easy access for this change of setup shall be given. Realignment of the downbeam mirror is needed after the change.

During operations it shall be expected that over time the mirror surfaces might degrade. Replacement of the mirrors is currently not estimated, due to the unexplored nature of FEL x-ray beam interaction with the surface of the mirror.

3.4. Lifetime

The expected service life of the device is 10 years.

4. Optical Requirements (Physicists Input)

Physics requirements (including optical requirements) are set forth in SP-391-000-34 "Physics Specifications for the LUSI HRM System", reference [03]. The FEL beam characteristics used for design purposes including full width half maximum (FWHM) spot size, energy per pulse and spectral range are defined in reference [03] and [05].

5. Mechanical Requirements

5.1. Performance Requirements

- The mirror system shall have greater than 10^4 contrast between the fundamental and 3rd harmonic over a fundamental energy range of 6 - 8.5 keV.
- The mirror system shall preserve the transverse coherence of the FEL radiation to the highest extent achievable.
- The throughput of the mirror system shall be greater than 80%.

- The mirrors must not damage or degrade when exposed to the full LCLS flux in NEH Hutch 3, where the x-ray spot size is 220 μm FWHM and energy per pulse is 1 mJ, across the 6-25 keV spectral range without degradation due to radiation damage.
- The clear aperture of the mirror system shall be greater than 1 mm in the Y direction.

  8.0σ width of the FEL radiation in the Y direction
  FWHM =220μm = 2.3548σ, so 8.0σ = 747μm

- Each mirror shall not alter the beam divergence more than 50% of the natural FEL divergence.

5.2. Physical Specifications of the Mirrors

5.2.1. Material and Size

- Material
  - Si <100> or Si <110> or Si <111>
- Size
  - Width
    - 30 mm (+/- 0.5 mm)
    - 15 mm optical surface
  - Length: The length of the mirrors shall be at least 5 σ of the FWHM beam, when the mirrors are set at 0.2° incident angle:
    - FWHM (4KeV) = 327μm, 5σ = 694μm; .
      0.694mm/sin 0.2° = 198.8mm
      (1mm aperture, 200mm optical surface = 0.286° incident angle)
    - 250 mm (+/- 0.5 mm)
    - 200 mm optical surface
  - Thickness
    - 20 mm (+/- 0.5 mm), also vendor driven for required geometry

5.2.2. Surface Finish

- Polish
  - One side of the mirror is polished
- Coating
  - none

5.2.3. Surface Finish Quality

- Geometry
  - Shape
    - Tangential cylinder
  - Sagittal radius
    - > 1 km
  - Tangential radius
    - > 10 km
- Surface quality
  - Tangential slope error
    - < 2.5 μrad (rms, Roughness Measurement System)
  - Sagittal slope error
    - < 8.0 μrad (rms)
  - Height error
    - < 2nm (rms)
  - MSFR (Mid Spatial Frequency Roughness)
    - 2.5 nm (rms)
  - HSFR (High Spatial Frequency Roughness)
    - 4nm (rms)

5.3. Positioning Requirements

- Individual degrees of freedom for each mirror (in the order of importance, highest importance first). Based on the LUSI coordinate system [02]-[5.1 Coordinate Systems and Beamline Orientations].
  - Pitch dynamic, motorized
  - Y dynamic, motorized
  - Roll static, aligned
  - X dynamic, motorized
  - Z static, aligned
  - Yaw static, aligned
- The range of the motion is defined by the minimum and maximum value. The repeatability defines the range value allowed. The resolution defines the highest value step size allowed. The stability defines the stability over time. The speed of motion is

nominal 3000 full steps per second (15 revolutions per second). Micro stepping of the motor is possible.

- Independent pitch adjustment of the mirrors is needed.
  - $Pitch_{M\ upbeam}$
    - min. -0.2 degree
    - max. +2.0 degree
    - repeatability +/-0.005 degree
    - resolution 0.002 degree
    - min. stability 0.00054 degree over 1 h
      9.4 μrad (10% x 0.220 mm / 2345 mm)
  - $Pitch_{M\ downbeam}$
    - min. -0.2 degree
    - max. +2.0 degree
    - repeatability +/-0.005 degree
    - resolution 0.002 degree
    - min. stability 0.00054 degree over 1 h
      9.4 μrad (10% x 0.220 mm / 2345 mm)
- Vertical translation (Y direction) of the mirrors must be performed to center the incident beam on the mirrors to within 10% of the mirror length.
- The mirrors shall have the necessary stability, both long term and short term, such that the beam pointing is not altered by more than 10% of the spot size. The expected spot size is 220 μm (0.0087") for the NEH-XPP and 500 μm (0.0197") for the FEH-XCS.
- The downbeam mirror must also be able to be removed away from the x-ray beam path independently of the upbeam mirror, to facilitate liquid interface scattering experiments.
- Both mirrors must be able to be removed away from the beam, with a 12.7 mm stay-clear, to enable "pass-through" of the third harmonic.
  - $Y_{M\ upbeam}$
    - min. -2.0 mm
    - max. +13.2 mm (12.7 + 0.5 mm, 125 mm @ 2 degree)
    - repeatability +/-0.005 mm
    - resolution 0.002 mm
    - min. stability +/-0.022 mm over 1h (10% x 0.220 mm)
  - $Y_{M\ downbeam}$
    - min. -13.2 mm (12.7 + 0.5 mm, 125 mm @ 2 degree)
    - max. +13.7 mm (12.7 + 1.0 mm, 125 mm @ 4 degree)
    - repeatability +/-0.005 mm
    - resolution 0.002 mm
    - min. stability +/-0.022 mm over 1h (10% x 0.220 mm)

- The roll of the mirror surfaces shall be aligned to within +/-1 degree of the x-axis.
  - Roll reference x-axis
    aligned to < 1.0 degree
    < 0.0174 rad (0.0174 x 30 mm = 0.52 mm)
- Horizontal translation (X direction) of each mirror is needed to adjust to location of the beam on the mirrors if damage is detected or if a multicoated mirror is used.
  - X min. -15.0 mm (half mirror width)
    max. +15.0 mm (half mirror width)
    repeatability +/-0.050 mm
    resolution
    min. stability 0.010 mm
- The yaw of each mirror shall be aligned to within +/-1 degree of the z-axis.
  - Yaw reference z-axis
    aligned to < 1.0 degree
    < 0.0174 rad (0.0174 x 250 mm = 4.35 mm)
- The Z of each mirror shall be aligned to within +/- 5 mm, when the mirror pitch is at 0 degree pitch.
  - Z reference z-axis
    aligned to +/- 5 mm

5.4. Cyclic Requirements

The motorized degrees are expected to have the following frequency of use:

- Pitch 50x / year 2h
- $Y_{M\ upbeam}$ 50x / year 2h
- $Y_{M\ downbeam}$ 50x / year 2h
- X <10x / year

The attached bellows shall be able to follow all maximum travel within the described cycle.

5.5. Mechanical Interfaces

5.5.1. Layout

The current layout has the following order:

Bellows - Mirror upbeam - Bellows - Mirror downbeam - Bellows

The space constraints are:

- X-axis
  - X dimensions are not critical.
  - Interference with adjacent beam line components (e.g. beam containment) shall be avoided.
- Y-axis
  - +Y dimensions are not critical.
  - –Y shall be minimized to fit above the raft.
- Z-axis
  - The overall Z length of the devices shall be minimized.
  - The cumulative length of all the devices on the optics raft in hutch 3 (XPP) must fit on the Optics And Diagnostics Table between the LUSI Pulse Picker and the LUSI Slit System, upbeam of the XPP Diffractometer , including three required bellows. Target length is 0.98m.
  - The cumulative length of all the devices on the optics raft in hutch 4 (XCS) must fit on the Optics And Diagnostics Table between the LUSI Attenuators and the LUSI Defining Slits, upbeam of the XCS Diffractometer , including three required bellows. Target length is 0.98m.

The mode of operation for the downbeam mirror to reflect either parallel to the incoming beam or reflect the beam further down (positive pitch) shall be switched mechanically by removing the mirror and reassembling it in a rotated orientation. Due to that the mirror tanks shall be reasonably accessible. A replacement of the mirror might become necessary in the future and shall be feasible.

5.5.2. Beamline Components Interface

The flanges of the vacuum system that connect to the LCLS beam line shall be 6 inch diameter CF flanges, non-rotatable up-beam and rotatable down-beam.

5.5.3. Raft

The HRM shall be supported by the raft [09] as described in section 5.13.

5.5.4. Hardware

The connecting bolts to the mating beamline component flanges shall have the option to be inserted from the bellows side.

5.6. Vacuum

This device will be used in a Vacuum of 10^{-7} Torr. The device's vacuum sealing surfaces shall be leak tested. [01]

All lubricants, cutting fluids, etc., used in manufacturing shall be "sulfur-free". SLAC document No. SC-700-866-47 is a compendium of SLAC approved lubricants. The use of sanding discs, abrasive paper or grinding wheels is typically prohibited. In special circumstances good vacuum practices should be followed when grinding and polishing is required. This process shall be reviewed and approved by the engineer for its vacuum compatibility.

All parts and subassemblies shall be cleaned for UHV. Once parts are cleaned for vacuum, handle only with clean latex or nitrile gloves in/on a clean room/surface. This includes all subassemblies. For storage or transportation, place in clean sealed vacuum grade plastic bag that has been back-filled with nitrogen.

5.7. Materials

Materials shall be compatible with the use in UHV environment as specified in section 5.6. The system shall be able to withstand a "bake" the system at high temperature (250°C).

All parts and materials for the device shall be new and compatible with the performance requirements of this specification. Mil source certifications, including heat number, chemical analysis for all materials used in the manufacturing of the device shall be furnished as specified [01].

Use of Teflon is prohibited.

5.8. Thermal Issues

The mirrors shall not be cooled.

The temperature gradient for the components shall be limited per section 3.2.

5.9. Structural Issues

Each of the mirrors shall be independently supported from a mounting rail. Each mirror shall have independent motion control. The vacuum load on the system needs to be taken into account.

5.10. Precision motion

The precision of each degree of freedom is listed in section 5.3. Stepper motors and stage gearing must provide adequate resolution with the goal of repeatability and stability.

5.11. Alignment/Fiducialization

Ideally the support shall have 6 independent struts in an orthogonal orientation. Reference points for scales and/or tooling balls receptacles (including redundant spares) shall be provided and suitable for their usage. Redundancy example: Instead of 3 tooling balls receptacles, a minimum of 4 tooling balls receptacles shall be provided.

Fiducialization references shall be clearly marked and protected if necessary.

5.12. Stability

Critical stability is listed in section 5.3 for the individual degrees of freedom.

5.13. Kinematics / Supports

Each mirror system shall have three static degrees of freedom and three motorized degrees of freedom for remote operation. The priority of one motion over another is defined in section 5.3.

- Motorized / Dynamic
  - X
  - Y
  - Pitch
- Aligned / Static
  - Z
  - Roll
  - Yaw

6. Electrical Requirement

The electrical interface is defined in the Interface Control Documents [05] [06] [08].

7. Inspections, Test Provisions and Testing

- Part quality control
- Component test fit
- Motion range check
- Leak check
- Motion check with limit check and stability check of critical directions
- Changes reserved

8. Major Interfaces

- Beamline components interface as defined in section 5.5.2.
- Raft mounting interface as defined in section 5.5.3.
- Alignment interface points as defined in section 5.11.
- Electrical interface as defined in section 6.

9. Controls

9.1. Motion control

- Remote operation of the mirrors is required during normal operation. Required motion is defined in section 5.3.
- If the downbeam mirror must be flipped, then remote operation for the flip is not necessary (breaking vacuum is acceptable).

9.2. Feedback / Encoders

- A viewport shall be provided to view the mirrors either for damage or to image the beam on the mirror surface with a scintillator. Viewable diameter minimal 50 mm.
- LVDT with limit switches or encoders on primary motorized degrees of freedom
  - Y
  - Pitch
- Limit switches or encoders on secondary motorized degrees of freedom
  - X

10. Radiation Physics

The mirrors shall be protected by a chin-guard.

11. Others

11.1. Ports

- Upbeam 5.5.2 Beamline Components Interface
- Downbeam 5.5.2 Beamline Components Interface
- View port 9.2 Feedback / Encoders

Additional ports for the mirror tanks, as needed

- Pump port 2.75" CF
- Spare port 2.75" CF

12.Environmental Safety and Health Requirements

12.1. Earthquake

No special design requirements shall be necessary relative to earthquake safety issues.

12.2. Radiation Physics

The HRM shall be located in radiological controlled areas and there are no radiation physics issues at the device level.

12.3. Pressure Vessel / Vacuum Vessel

The HRM shall be designed for use in an Ultra High Vacuum (UHV) environment with the appropriate safety factors.

Pressure relief safe guard (burst disc) shall be provided at adjacent assemblies.