| PHYSICS REQUIREMENT DOCUMENT (PRD) | Doc. No. SP-391-000-24 R0 | LUSI SUB-SYSTEM CXI |
|---|---|---|

# Physics Requirements for the CXI 0.1 micron Kirkpatrick-Baez (KB) Mirror System

| | | |
|---|---|---|
| Sébastien Boutet<br>CXI Scientist, Author | Signature | Date |
| Paul Montanez<br>CXI System Engineer | Signature | Date |
| | Signature | Date |
| | Signature | Date |
| Darren Marsh<br>LCLS Quality Assurance Manager | Signature | Date |
| Nadine Kurita<br>LUSI Chief Engineer | Signature | Date |
| Tom Fornek<br>LUSI System Manager | Signature | Date |

| Revision | Date | Description of Changes | Approved |
|---|---|---|---|
| R0 | 23JUN08 | Initial release | |
| | | | |
| | | | |

DCR

## Table of Contents



# 1. Overview

The CXI 0.1 micron Kirkpatrick-Baez (KB) System (KB0.1) will consist of two orthogonal reflective mirrors at grazing incidence. Each mirror focuses the X-ray beam in one direction. This document describes the requirements for a KB system capable of producing a desired focal spot on the order of 100 nm x 100 nm for the CXI instrument.

The coordinate system is defined in Mechanical Design Standards Supplement DS-391-000-36.

# 2. Performance Requirements

**2.1.** The KB0.1 system shall focus the beam to a desired spot size on the order of 100x100 $nm^2$ FWHM at the interaction plane, inside the CXI sample chamber described in document PRD 391-000-20, *Physics Requirements for the CXI Sample Chamber*, over at least the 2 – 9 keV spectral range and extending to as close to 25 keV as possible.

**2.2.** The size of the focal spot will depend on the photon energy because the location of the source depends on the photon energy but in order to produce the desired focal spot, the average focal length of the two mirrors shall be 0.7 meters. Due to the short focal length of the mirrors and their length requirements, described in Section 3, each mirror will have a significantly different focal length. The beam produced will therefore be elliptical at the focus. For example, if the first mirror has a 0.5 m focal length and the second has a 0.9 m focal length, then a focus of 68x120 $nm^2$ FWHM (assuming perfect optics) will be produced at 8.3 keV. The beam will get larger for lower energy photons.

**2.3.** The KB0.1 system shall preserve the transverse coherence of the FEL radiation to the highest extent achievable. This will be achieved by very accurate figuring and polishing of the mirrors as described in Section 5.

**2.4.** The reflectivity of the KB0.1 system shall be greater than 75% over at least the 2 – 9 keV spectral range and extending to as close to 25 keV as possible.

**2.5.** The mirrors shall not suffer damage or degrade when exposed to the full LCLS beam intensity calculated based on the parameters given in LCLS PRD # 1.1-014. The unfocused beam size at the mirrors is given in Table 2-1. The FWHM is 2.35 times the standard deviation.

| Energy (keV) | FWHM of the beam at the mirror (µm) | Standard deviation (σ) of the beam at the mirror (µm) |
|---|---|---|
| 2 | 1445 | 615 |
| 4 | 813 | 346 |
| 6 | 602 | 256 |
| 8.265 | 491 | 209 |
| 24.795 | 162 | 69 |

**Table 2-1:** Beam size at the location of the KB0.1 system

**2.6.** The mirror holder system shall also not suffer damage when exposed to the full LCLS beam intensity. The material of the holder could get ablated by the LCLS beam and cause some foreign material to be deposited on the mirrors. This shall be prevented using either physical radiation protection such as light materials or via interlocks and limits on motions, or by designing a mechanical system that has no possibility of being illuminated by the LCLS beam .

**2.7.** The upstream edge of each mirror will have a surface that is very close to normal to the LCLS beam. This upstream face shall be protected with an appropriate radiation-resistant shield to prevent damage to the mirrors due to the x-ray beam.

**2.8.** The thermal loading on the mirrors from the full power of the LCLS beam shall be considered in the design to ensure proper stability consistent with all positioning and performance requirements.

**2.9.** The KB0.1 system shall deflect the beam toward the positive x direction (as defined in DS-391-000-36) in the horizontal plane (xz).

# 3. Size Requirement

**3.1.** The clear aperture of the mirrors of the KB0.1 system shall be large enough to at least match the acceptance of the LCLS Hard X-ray Offset Mirrors (HOMS) described in LCLS PRD # 1.5-005 over the entire 2 - 8.3 keV spectral range.

**3.2.** The KB0.1 mirror system shall be long enough at the desired angle of incidence to accept at least 5 standard deviations (5σ) of the Gaussian beam over the 4-8.3 keV range and the design goal shall be to have the acceptance as close to 5σ as possible over the 2-4 keV range.

**3.3.** A strip of at least 5 mm and no more than 20 mm shall be present at the ends of the mirrors in the long direction to allow clamping. The total length of the mirrors will be the sum of the useable length of the mirrors and twice the length of this extra strip. The useable length of the mirrors is the clear aperture divided by sin(θ) where θ is the angle of incidence of the beam on the mirror.

**3.4.** A strip of at least 5 mm and no more than 20 mm shall be present on the sides of the mirrors to allow clamping. The total width of the mirrors will be the sum of the clear aperture width and twice the width of this extra strip.

# 4. Positioning Requirements

**4.1.** Each of the two mirrors in the KB0.1 system shall have motorized motion for x, y, pitch, yaw and roll and these motions shall satisfy requirements 4.4, 4.5, 4.6, 4.7, 4.8 and 4.9. The range of motion, accuracy, repeatability and stability for each motion is listed in Table 4-1.

**4.2.** The position of the two mirrors in the z direction shall be controlled (either through precise machining and surveying or with motorization) to within half the Rayleigh length of the focus so that the beam is not astigmatic at the focus, that is both mirrors focus the beam at the same location in z. The Rayleigh length for a 68 nm FWHM focus at 8.3 keV is 17 μm. Therefore, the mirrors shall be positioned to within no worse then 8 μm with respect to each other along the z direction.

**4.3.** The KB0.1 system shall be aligned into a position placing the focal point at the proper plane in the sample chamber, described in PRD 391-000-20, *Physics Requirements for the CXI Sample Chamber*, to within an accuracy of 100 μm along the z direction. Fine adjustment of the focus position in the Sample Chamber will be accomplished by moving the Sample Chamber (PRD SP-391-000-20) using the Precision Instrument Stand (PRD SP-391-000-63).

**4.4.** It shall be possible to translate the KB0.1 system out of the beam in the xy plane so that a stay-clear radius of 0.5" exists to let beam pass.

**4.5.** It shall be possible to position each mirror individually to within 4 μm in both the x and y directions over a range equivalent to twice the clear aperture of the mirrors.

**4.6.** It shall be possible to set the grazing angle (pitch) of each mirror to within 0.5 μrad accuracy.

**4.7.** It shall be possible to control the perpendicularity of the mirrors to within 5 μrad accuracy. This means the roll angle of each mirror shall be controlled to this accuracy.

**4.8.** The in-plane rotation (yaw) of each mirror shall be controlled to an accuracy of 1 mrad.

**4.9.** The mirrors should have the necessary stability, short term (over a few minutes) and shot-to-shot, so that the beam position relative to the sample chamber at the focal plane is not altered by more than 10 nm.

| Motion | Nominal Position | Range | Resolution | Repeatability | Stability |
|---|---|---|---|---|---|
| x | 0 | $-10$ mm $< x <$ 2 mm | 4 μm | 4 μm | 0.01 μm |
| y | 0 | $-5$ mm $< y <$ 5 mm | 4 μm | 4 μm | 0.01 μm |
| Grazing angle ($\theta$) | 3.4 – 5.5 mrad | 3 mrad $< \theta <$ 6 mrad | 0.5 μrad | 0.5 μrad | 0.01 μrad |
| In-plane rotation ($\psi$) | 0 | $-10$ mrad $< \psi <$ 10 mrad | 1 mrad | 1 mrad | 0.1 mrad |
| Perpendicularity ($\varphi$) | 0 | $-10$ mrad $< \varphi <$ 10 mrad | 5 μrad | 5 μrad | 0.1 μrad |

**Table 4-1:** Motion requirements for each mirror in the KB0.1 system.

# 5. Mirror Surface Requirements

**5.1.** Each mirror in the KB0.1 pair shall have the proper elliptical shape required to achieve the focal length needed to produce a desired focal spot on the order of 100 x 100 $nm^2$. This shape could be obtained by dynamical bending or machining of a curved surface.

**5.2.** For a well-corrected optical system leading to a minimum of 80% of the incident intensity found in the central Gaussian peak at the focal plane, the Maréchal criterion defining the maximum tolerable rms height error ($h_{rms}$) must be satisfied.

$$h_{rms} \leq \frac{\lambda}{14\sqrt{N}\,2\alpha}$$

where $N$ is the number of reflective optics, $\alpha$ is the incidence angle on the optic and $\lambda$ is the wavelength of the light . For the KB0.1 system, $N$ =2, $\alpha$ is determined by the surface coating material and $\lambda$ will range from 0.62-0.05 nm at 2 keV and 25 keV respectively.

**5.3.** It shall be required that the Maréchal criterion is satisfied over a length scales of 1 mm up to the size of the useable length of the mirror at 8.3 keV, or $\lambda$ =0.15 nm for the angle of incidence that will be chosen to satisfy requirements 2.4 and 2.5. This requirement only applies over the useable area of the mirrors and not over the extra surface area around the edges of the mirrors, described in Requirements 3.3 and 3.4.

**5.4.** The mid-spatial roughness of the mirrors in the $10^{-3}$ to 0.5 $\mu m^{-1}$ frequency range shall be less than 0.25 nm rms. This requirement only applies over the useable area of the mirrors and not over the extra surface area around the edges of the mirrors, described in Requirements 3.3 and 3.4.

**5.5.** The high-spatial roughness of the mirrors in the 0.5 to 50 $\mu m^{-1}$ frequency range shall be less than 0.25 nm rms. This requirement only applies over the useable area of the mirrors and not over the extra surface area around the edges of the mirrors, described in Requirements 3.3 and 3.4.

**5.6.** The tangential slope error of the mirrors shall be less than 0.25 μrad rms. This requirement only applies over the useable area of the mirrors and not over the extra surface area around the edges of the mirrors, described in Requirements 3.3 and 3.4.

**5.7.** The mounting of the mirrors shall not distort the elliptical figure of the mirror by more than the natural figure errors in the case of pre-profiled mirrors. That is the clamping system shall not introduce figure errors that are in excess of the Maréchal criterion described in Requirement 5.2.

**5.8.** If the engineering solution of choice involves bendable mirrors, the figure and roughness requirements (5.2, 5.3, 5.4, 5.5) shall be met when the mirror is flat and when it is bent to the proper elliptical shape.

**5.9.** In order to maximize the energy range over which the KB0.1 system satisfies requirements 2.4 and 2.5, it may be useful to have 2 different coating layers on the mirrors. The design effort shall consider this alternative and not preclude it.

# 6. Interlock Requirements

**6.1.** The 0.1 micron KB system shall be interlocked with the 1 micron KB system (PRD 391-000-25), the PPS Photon Stopper and the MPS system to guarantee that the beam will not impinge on either set of KB mirrors during the exchange from one KB system to the other.

**6.2.** Only a small range of translations (2 mm) for fine-tuning the system shall be allowed while the LCLS beam in on. The PPS photon stopper shall always be closed when the mirrors are moved over a distance larger than 2mm from a nominal center position.

# 7. Vacuum Requirements

**7.1.** The KB0.1 system shall reside and operate in an Ultra-High Vacuum environment to prevent deposition of unwanted material on the surface of the mirrors. A pressure of $10^{-9}$ Torr or better shall be required and the appropriate vacuum practice for the design, manufacturing, and installation of the system components shall be implemented.

**7.2.** The KB0.1 system shall allow for direct viewing of the mirrors during operation.

**7.3.** The vacuum chamber design shall allow the use of an interferometer to verify the angles of the mirrors. Viewports shall be present to allow the use of this interferometer. The resolution and other details of the interferometer are to be specified at a later date and the design of the vacuum chamber shall have 6 viewports (facing x, y, and z directions for each mirror) for the future addition of the interferometer.

**7.4.** Differential pumping shall be included on both sides of the KB0.1 mirrors to maintain the lower pressure of the mirror environment compared to the rest of the beam line.

**7.5.** It shall be possible to easily access the mirrors for maintenance. This could be achieved with a removal top part of the chamber in the area of the mirrors for example.

**7.6.** The vacuum enclosure of the mirror system shall have only metal seals in order to reach the necessary vacuum level.

**7.7.** The vacuum enclosure shall have two ports for vacuum gauges.

**7.8.** The vacuum enclosure shall have one port for rough pumping.

**7.9.** The vacuum enclosure shall allow for mounting an ion pump under the enclosure.

# 8. Controls Requirements

**8.1.** All motorized degrees of freedom of the KB0.1 system shall be controlled, monitored and archived remotely via the instrument control system.

**8.2.** Feedback from diagnostic devices shall be used to maintain the performance of the system over time. It shall be possible to use this feedback to correct the mirror positions or figures at a rate of 1 Hz.

**8.3.** Software limits shall be used to implement requirement 6.2.

**8.4.** The software limits consistent with Requirements 6.1 and 6.2 shall be user-modifiable with password protection.

**8.5.** Every motor position of the KB0.1 system shall be locked by the user when the 1 micron KB system is aligned and in use. The motor positions shall be unlocked by entering a valid password.

**8.6.** Every motor position of the KB0.1 system shall be locked at the request of the user at any given time. The motor positions shall be unlocked by entering a valid password.

**8.7.** It shall be possible to set up scans of a selected axis of motion and monitor the effect on the beam using a user selected monitor from the list of all available CXI monitors, which include the

CXI 2D X-ray Detector (LCLS PRD # 1.6.002), all the CXI Pop-in Profile Monitors (PRD SP 391-000-04), CXI Pop-in Intensity Monitors (PRD SP 391-000-09) and CXI Intensity-Position Monitors (PRD SP 391-000-08).

# 9. Miscellaneous Requirements

**9.1.** The mechanical design of the 0.1 micron KB System shall be identical to that of the 1 micron KB System. Only the curvature of the mirrors shall differ between the two systems.

**9.2.** The vacuum enclosures of the KB0.1 and KB1 systems are not required to be the same. Only the internal parts are required to be identical.

**9.3.** A fluorescent screen on a retractable linear feedthrough shall be located upstream of the first mirror to locate the LCLS beam for rough alignment of the system.

# 10. Interface Requirements

**10.1.** The close proximity of the KB0.1 system to the CXI Sample Chamber (PRD SP-391-000-20). In order to produce a focal spot that meets the requirements of Section 2, it may be necessary for the mirror system to be mounted inside the Sample Chamber enclosure. In that case, differential pumping shall be included to separate the low pressure vacuum required for the KB mirrors and the higher pressure of the chamber.

**10.2.** The KB0.1 mirrors shall remain fixed relative to the incident beam when the sample chamber is moved. The motion of the Sample Chamber shall not cause the mirrors to move even if the mirrors are mounted inside the Sample Chamber. A mount through a bellows may be required to decouple the mirrors from the chamber motions.

**10.3.** If the engineering solution of the Sample Chamber and KB0.1 mirror system interface involves 2 separate chambers, the KB0.1 chamber shall either be reentrant into the Sample Chamber or the z lengths of the Sample Chamber and the mirror chamber shall be short enough to allow the focal spot size requirements to be met.

**10.4.** The xy cross-section of the KB0.1 mechanical system shall be minimized to facilitate the integration and interface of the system with the Sample Chamber.

**10.5.** The length of the mirrors will be chosen to satisfy the performance requirements of Section 2 and shall not be minimized. However, the mechanical system holding the mirrors inside the vacuum enclosure shall be kept as short as possible.

**10.6.** The KB0.1 vacuum enclosure (assuming the mirrors are not located inside the Sample Chamber) shall be interchangeable with the CXI Detector Stage (PRD SP-391-000-28) so that the Detector Stage can be mounted upstream of the Sample Chamber.