ENGINEERING SPECIFICATION DOCUMENT (ESD)	Doc. No. SP-391-000-94 R0	LUSI SUB-SYSTEM DCO LO Monochromator

LUSI Large Offset Monochromator Engineering Specification

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R0	17APR09	Initial release	

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1. Scope:

This document defines the engineering requirements for a Large Offset Monochromator (LOM) to deflect the x-ray beam 60 cm parallel to the incoming beam and select a specific photon energy from the incoming x-ray spectrum. The selected photon energy must be tunable from 4 keV to 25 keV.

2. Glossary / Definitions:

Accuracy: The absolute error in the ability to establish a specified location and angle with respect to the origin of a fixed coordinate system.
ESD: Engineering Specification Document
FEH: Far Experimental Hall
PRD: Physics Requirement Document.
Range: The total available motion with respect to a fixed coordinate system origin.
Repeatability: the absolute error in the ability to successively reestablish a specified location/angle, with respect to the origin of a fixed coordinate system.
Resolution: The uncertainty of the measurement of location/angle with respect to the origin of a fixed coordinate system.
Stability: The amplitude of motion over a specified time.

3. Documents, Specifications and Codes:

3.1. SLAC Specifications:

AP-391-000-59	Engineering Review Guidelines
DS-391-000-36	Design Standards Supplement
SLAC-I-720-0A24E-002	Specification for Seismic Design at the SLAC
SP-391-000-16	offset Monochromator Physics Requirements
SP-391-001-35	XCS Instrument Physics Requirements
SP-391-001-29	XCS Instrument Engineering Specification

3.2. Industry Specifications and Codes:

NEC, NFPA 70:	National Electric Code
NEC, NFPA 70E:	Electrical safety in the Workplace
CBC 2007:	California Building Code, 2007

4. Large Offset Monochromator Summary:

The Large Offset Monochromator uses a pair of crystals to deflect the LCLS x-ray beam parallel to the incoming path and select a specific photon energy from the incoming spectrum. The monochromatic x-ray beam is then used to perform experiments.

Since the diffraction angle of a given crystal is photon energy dependant, the Monochromator must be tunable over a wide energy range. The crystals motion must be performed with precision translations and rotations to accomplish appropriately their function. The range of motion of the crystals is also dependent on the selection of crystal material. Since the second crystal must diffract the selected photon energy at exactly the same angle as the first crystal, the exiting beam is constrained to exit the monochromator parallel to the incoming beam.

The energy of the x-rays delivered to an experiment are not changed continuously, but are fixed for a given experiment. During an experiment, the crystals must remain precisely aligned, delivering the selected photon energy to the sample, for the duration of the experiment.

The physics requirements of the Large Offset Monochromator are described in SP-391-000-16, Offset Monochromator Physics Requirements.

5. Large Offset Monochromator Use and Location:

The Large Offset Monochromator will be used by the XCS instrument. The XCS installation is located upstream of XCS Hutch 4, in the X-Ray Transport Hall of the LCLS facility. The XCS instrument is a multipurpose instrument which can utilize a wide variation of x-ray photon energies.

The location of the Large Offset Monochromator for the XCS instrument will be in the X-ray Transport Tunnel (XRT). The XRT is expected to have a temperature stability of ±1F. See Sec. 14 for more details regarding this aspect.

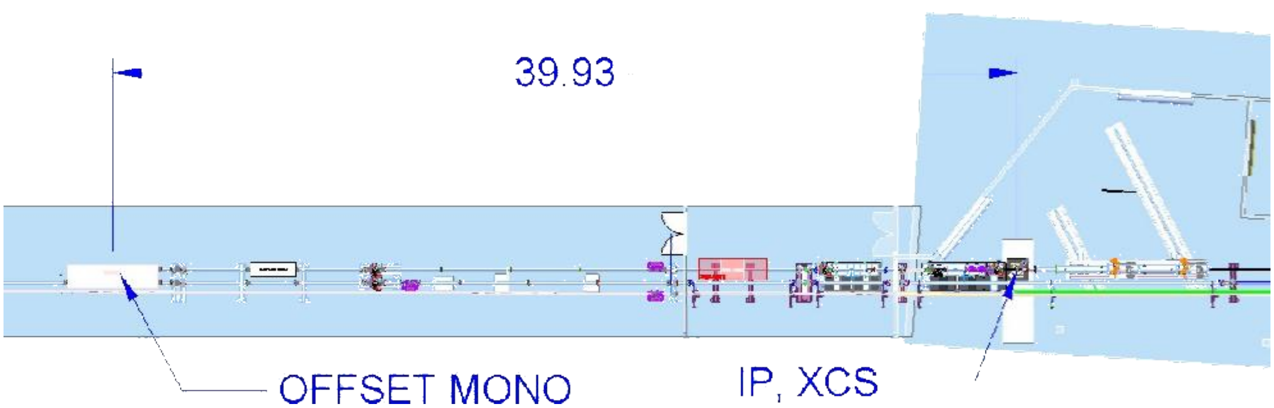

Figure 1 Large Offset Monochromator location in the XRT

The monochromator must be capable of using either Silicon and/or Diamond single crystals with various possible lattice orientations. The first crystal must be capable of being remotely removed from the beam path to allow the x-ray beam to propagate, uninterrupted through the monochromator for use in downstream on-axis experiments. Both crystals must be precision adjustable in angle to select photon energy and deliver beam at 600 mm offset and parallel to the incoming beam.

The crystals to be used in the monochromator will be provided by SLAC. The mounting strategy for the crystals will be agreed upon by collaborative design between SLAC and the monochromator fabricator. The possibility of using a thin first crystal, allowing to multiplex the beam is a possible upgrade. This could be done with an upgrade of the first crystal mount.

6. Local Coordinate System

The LCLS local coordinate systems at the monochromator installed locations are defined in DS-391-000-36 “Design Standards Supplement” and located in MR-391-750-00 “MASTER BEAM LINE”. The coordinate systems are right hand Cartesian systems with Z+ axis in the direction of X-Ray propagation, parallel to the floor, the X+ axis parallel to the floor and Y+ vertical up.

A device coordinate system may be used for design of the monochromator. A device coordinate system at SLAC is normally defined by the responsible engineer with the origin placed at a point significant to the device and the coordinate axes oriented parallel to the local coordinate system. For the Large Offset Monochromator, the suggested device coordinate system location is on the incoming x-ray beam axis (1.4 m above the floor), centered between the input and output beam-line flanges. An alternate device coordinate system may be specified by the vendor, but must be communicated to the responsible SLAC engineer early in the preliminary design cycle.

The CAD software coordinate system axes orientations may be different than the device coordinate system axes for ease of design.

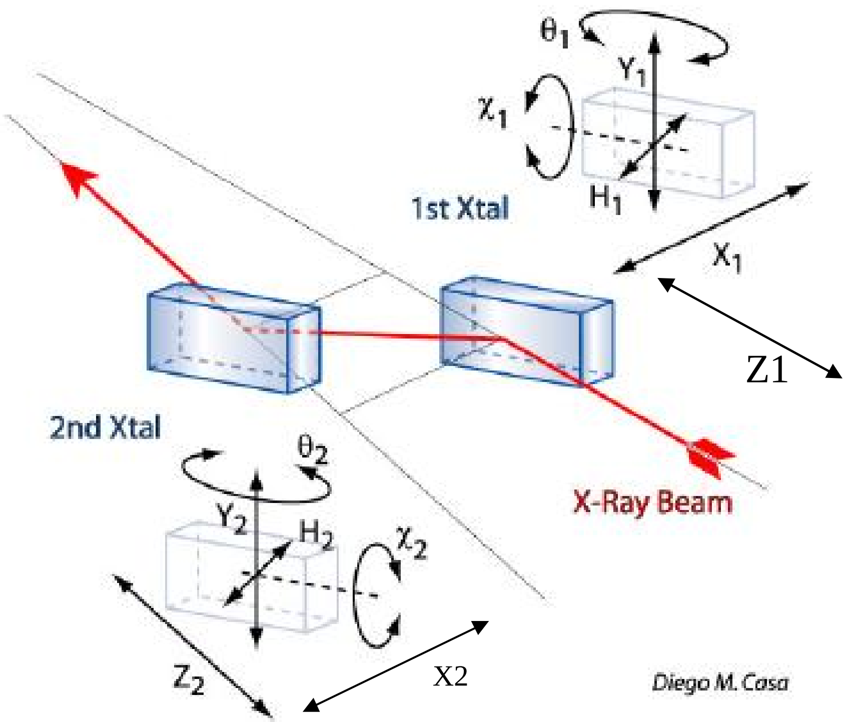

Figure 2 Crystal motions in device coordinate system notation

7. Crystal Selection

The selection of the proper crystal for the monochromator depends on the desired photon energy for a given experiment, given expected flux and given energy bandwidth. For the XCS instrument, the desired x-ray properties necessitate the use of two pairs of crystals to be used in the monochromator; Si (111) and Si (220). As a possible upgrade we use C* 111 or eventually C* (220). Table 1 shows the incidence angle (half the deflection angle) and longitudinal separation distance between the two crystals for Si and C* with (111) and (220) lattice orientations.

Crystal	H	K	L	4keV, λ=3.1Å		15.25keV, λ=0.81Å		25keV, λ=0.49Å	
				Θ [deg]	Mono Length [mm]	Θ [deg]	Mono Length [mm]	Θ [deg]	Mono Length [mm]
Si	1	1	1	29.62	357	7.45	2255	4.54	3758
C*	1	1	1	n.a.	n.a.	11.38	1430	6.92	2437
Si	2	2	0	n.a.	n.a.	12.22	1320	7.42	2265
C*	2	2	0	n.a.	n.a.	18.80	779	11.34	1436

If only Si (111) would be used for the XCS monochromator, the maximum separation distance between the crystals would be of the order of 3.4 meters. In order to make the monochromator crystal travel shorter, the use of two pairs of crystals is required. The photon energy where one would switch between Si (111) and Si (220) would be 15.25 keV. (see TN-391-003-25 Monochromator Crystals)

At 15.25 keV, Si (111) diffracts at and incident angle of 7.45 deg yielding a crystal distance of 2260 mm and Si (220) diffracts at and incident angle of 12.22 deg yielding a crystal distance of 1320 mm. Switching between the two crystals for XCS at 15.25 keV significantly reduces the required range of motion of the monochromator.

For the XCS instrument it is desired to switch between Si (111) and Si (220) using the same travel range of the XCS monochromator.

Though not indicated in Table 1, a maximum incidence angle of 45 degree (90 degree deflection) must be accommodated for in the monochromator design.

The crystal mount in the monochromator must be capable of crystal replacement in a timely manner to either replace a damaged crystal or to change crystal material to modify the delivered x-ray properties.

8. Large Offset Monochromator Crystal Motions

We proposed instead of placing the first crystal in a fixed position and to have the second crystal traveling the whole requested range (or vice versa) to have both crystals moving half the range of the required longitudinal translation.
In order to maximize stability it is desired that both crystals move in the Z direction an equal distance, keeping the crossing point in the vacuum chamber stationary. This yields a maximum motion of each crystal in Z of the order of 1250 mm for a any scattering angles (2θ). This yields identical motion requirements for each crystal in a pair. This is illustrated in **Figure 3**. This concept presents the major advantage to reduce the length of the overall translation of the crystals, but also provides a location where the beam will always go through (as indicated by the green circle). This position should be used for diagnostics to align the first crystal. This design is similar to a large offset (1.5meter) monochromator (but in vertical scattering geometry) currently in construction at DESY for the PETRA III synchrotron source.

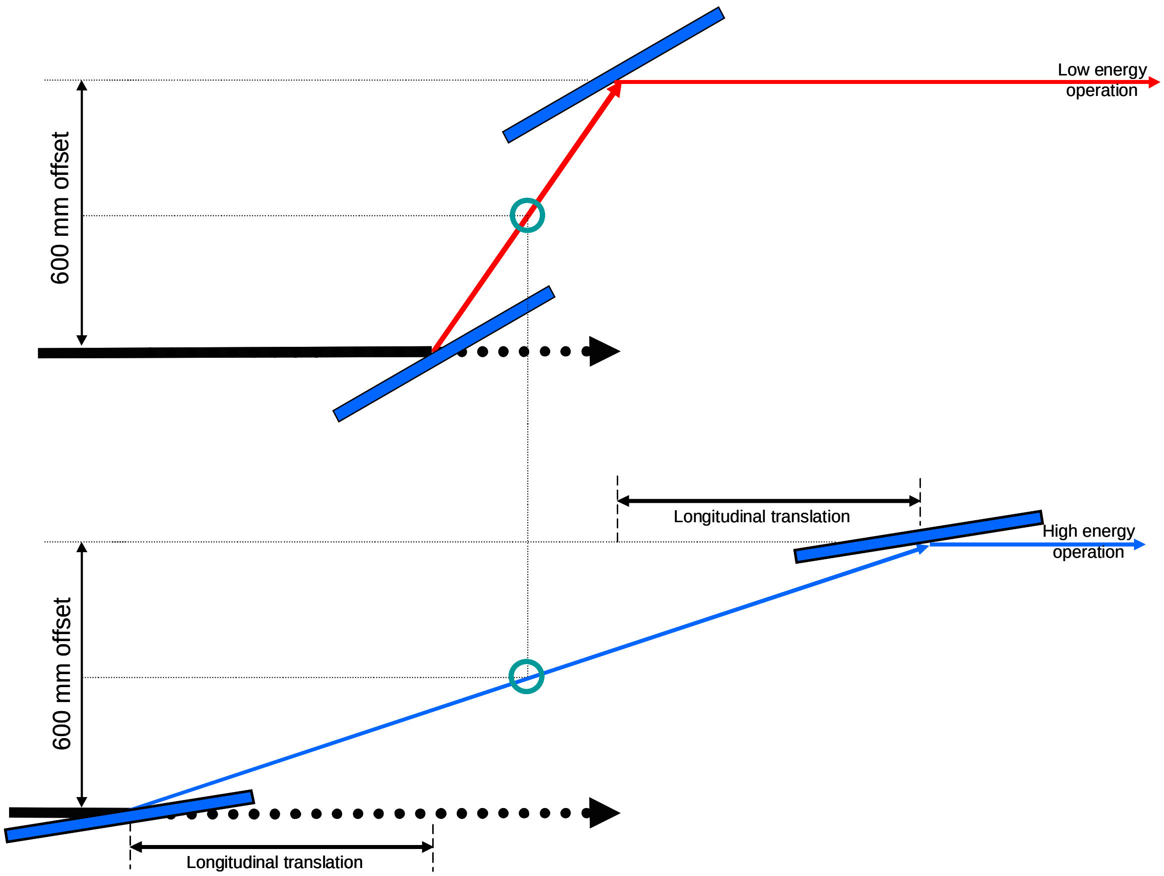

Figure 3 Description of the longitudinal motion of both crystal in order to cover the energy range. Low energy (top) and high energy (bottom) configuration.

This also allows to simplify the requirement as each crystal should describe the same motion with the same precision.

Each motion is described in the following sections and are illustrated in **Figure 2**. Each index (1,2) refers to the first and second crystal respectively.

8.1. Vertical translation of the monochromator

The large offset monochromator should have the capability to be aligned vertically as a complete assembly. This motion needs to be motorized and should cover a range of ±25mm with a resolution better than 100 microns.

8.2. Longitudinal Translations [Z1,Z2]

The horizontal translations [Z1], [Z2] are parallel to the incident beam (and also exit beam). This motion is used to adjust the horizontal position of each crystal and should have a range of approximately 1250mm.

It could consist of an in vacuum linear stage with fine pitch drive screw combined with gear reducer for torque enhancement and 5-phase motor or equivalent. It should have an optical linear encoder.

8.3. Transverse Translations [X1,X2]

The translations [X1,X2] are perpendicular to the incident beam. This motion is used to bring the vertical axis of rotation of each the first and second crystal into alignment with the incident beam and the exit beam respectively.
It could consist of an in vacuum linear stage with fine pitch drive screw combined with gear reducer for torque enhancement and 5-phase motor or equivalent.

Yaw, pitch error:5″/25 mm or less

8.4. Vertical Translations [Y1, Y2]

The vertical translations [Y1,Y2] are perpendicular to the incident beam axis and horizontal translations [X1,X2] respectively. This motion is used to adjust the height of the first crystal relative to the center of rotation of the positioning system. As we require to have at least 2 crystals on a holder vertically, these stages have to be positioned at the top of the tilt rotation stages [χ1,χ2] in order to bring the different crystals into the beam.
It could consist of an in vacuum linear stage with fine pitch drive screw combined with gear reducer for torque enhancement and 5-phase motor or equivalent.

Yaw, pitch error:5″/25 mm or less

8.5. Yaw Rotations [θ1,θ2]

Each rotation [θ1,θ2]is around its corresponding vertical axis [Y1,Y2] through the center of the diffraction surface of each crystal. [θ1] is used to select the angle of the first crystal with the incident beam and thereby selects the energy of the monochromatic beam. [θ2] is used to match the incident angle of the second crystal with the incident angle of the first one.
Each of them should provide a coarse and fine adjustment. It could consist of a worm gear rotation stage combined with a gear reducer and a 5-phase stepping motor and micro-stepping or equivalent. For the fine motion, it could consist of a piezo actuator with feedback.
Each of them should have an incremental rotary or optical encoder.
Each rotation should cover the complete range 0 to 90 degrees for alignment purposes.

8.6. Horizontal Translations [H1, H2]

The horizontal translations [H1,H2] are perpendicular to the diffraction surface of the crystals. This motion is used to bring the diffracting surface of each crystal into alignment with the axis or rotation and the incident beam.
It could consist of an in vacuum linear stage with fine pitch drive screw combined with gear reducer for torque enhancement and 5-phase motor or equivalent.

Yaw, pitch error:5″/25 mm or less

8.7. Pitch Rotation [χ1,χ2]

Each tilt angle motion is around the horizontal axis parallel to the diffracting surface of each crystal. This is motion is used for the first crystal to adjust the pointing of the exit beam from the

first crystal towards the center of the second one. For the second crystal, it is used to adjust the pointing of the exit beam from the second crystal to the experimental hutch.
Each of them should provide a coarse and fine adjustment. It could consist of a worm gear rotation stage combined with a gear reducer and a 5-phase stepping motor and micro-stepping or equivalent (coarse motion). For the fine motion, it could consist of a piezo actuator with feedback or equivalent
Each of them should have an incremental rotary or optical encoder.

8.8. Crystal Motion Summary

The motion requirements of each motor are summarized below.

Direction	Range (mm)	Accuracy (micron)	Repeatability (micron)	Resolution	Stability (micron / hour)
Z1,Z2	**≈1250**	±10 µm	**±20n.a**	**10 µm/step**	**<1.0**
X1,X2	±12.5	±5 µm	±0.5 µm	0.5 µm/step	<1.0
Y1,Y2	±12.5	±5 µm	±0.5 µm	0.5 µm/step	<1.0
H1,H2	±12.5	±5 µm	±0.5 µm	0.5 µm/step	<1.0
Direction	**Range**	**Accuracy (seconds)**	**Repeatability (seconds)**	**Resolution (seconds)**	**Stability (seconds / hour)**
Coarse θ1,θ2	**0-90°**	**≤ 20”**	**≤4”**	**0.18”/step**	**<0.05**
Fine θ1,θ2	**60”**	**0.02”**	**0.5”**	**0.01”**	**<0.05**
Coarse χ1,χ2	**±2°**	**0.5”**	**≤2”**	**0.1”/step**	**<0.05**
Fine χ1,χ2	**60”**	**0.05”**	**0.5”**	**0.01”**	**<0.05**

The combined stability of all motions must result in a pointing stability of the exit beam of 10 micron/hour measured at 45 m from the center of the monochromator. A testing plan for this requirement must be furnished at the preliminary design review.

9. Crystal Alignment Diagnostics

In order to properly align the crystals to transmit the desired photon energy, diagnostics must be included in the design of the monochromator. In a monochromator design where both crystals move, there is a common point where the diffracted x-ray crosses the chamber, as indicated by the green circle in **Figure 3**. This should be the most suitable location for placing such diagnostics for the alignment of the first crystal.
Upstream and downstream the monochromator, SLAC is providing some diagnostics that can be used to aid the alignment of the monochromator. The design and performances of such diagnostics will be provided by SLAC.
The scheme of diagnostics for the alignment procedure should be discussed with SLAC Staff.

10. Radiation Shielding

A shield should be installed to protect all motion components for each crystal and neighboring parts. The choice of the shielding material should be discussed with SLAC staff.

11. Device Alignment

The entire device must be aligned to the incoming x-ray beam sufficiently to connect the incoming and exiting vacuum bellows and to align the crystals on the ideal beam-line. The device mount must connect to the floor, 1.4 m below the ideal beam height. The floor mount must also be optically stable so as not to perturb the x-ray beam interaction point at the sample.

A six-strut support may be used in combination with a base cradle to provide six degrees of freedom in position adjustment of the device vacuum chamber in space. An alternative six-degree of freedom alignment support may be proposed by the bidder. The support provided must meet the alignment tolerance required as well as the stability requirement.

All mounts and connections must meet the SLAC seismic policy and must be reviewed for adequacy.

The stability of the device support stand and alignment stage must be factored into the pointing stability requirement noted in section 8.8.

At least 2 viewing ports should be provided at easily accessible point to permit the optical inspection of the crystals.
The design of the monochromator should also accommodate easy means to align the crystals relative to the x-ray beam. The use survey of monuments will be discussed with SLAC staff when the details of the vacuum chamber will start.

12. Vacuum System

The vacuum chambers and all in-vacuum components must be compatible with the operating pressure of 10^{-7} Torr or better with beam on. The delivered system is to be cleaned and ready for use the UHV environment it will be connected to. All vacuum components should be capable of withstanding a baking out temperature if required.
No materials that degrade under x-ray radiation environment should be used.

The monochromator vacuum chambers will be interconnected using conflate 6 inch flanges. It may be assumed that the minimum pumping speed on each of the three beam-line ports; incoming, outgoing and through, will be 50 Torr-liter per second. The vacuum requirement for inside the monochromator is better than 10^{-7} Torr and an optically clean environment. If additional pumping on the monochromator volume is required to meet the vacuum requirement, the pumps must be included in the monochromator design.

The configuration of the monochromator vacuum chamber is the responsibility of the party performing the monochromator design. It may be a monolithic chamber containing both crystals and interconnecting flight path. Alternatively, the monochromator may be an assembly of multiple chambers, one for each mirror and an interconnecting flight path and diagnostic chamber. Any proposed configuration must be capable of achieving the required stability of the crystal pair for the delivery of the monochromatic x-ray beam.

13. Local Obstruction Avoidance

Specific care has to be taken to provide clearance to the nearby beam-line to the south of the Large Offset Monochromator. The nearby beam-line stay clear is an eight inch cylindrical volume, located at 40 cm (X) on the opposite side of the beam deflection direction.

14. Special Requirements in terms of stability

- The 1st and 2nd crystal motion mechanisms shall perform a fixed exit monochromator. Therefore the motion drive assembly mounted on the support should be rigid to minimize any gravity induced errors or any twist in order to provide the required energy range.
- Vibrations during the operations are critical for the experiment. Therefore the monochromator is expected to have excellent performances with regard to vibrations and stability. Particular attention should be paid to the need to minimize vibrations in the assembly (as well as the choice of the support).
- To meet the requirements of stability and isolation from airborne, structure born noise and vibration sources, it is required that the motions of the stages shall be decoupled to their vacuum chambers (if multiple of them). The motion stage assembly should be mounted on a stable platform like synthetic granite which has inherent natural damping qualities.
- **The support of the motion stage assembly can be mounted on wedge jacks or equivalent to allow its height adjustment at the bottom of the support.**
- The location of the Large Offset Monochromator for the XCS instrument will be in the X-ray Transport Tunnel (XRT). The XRT is expected to have a temperature stability of ±1F. So far the temperature stability can not be guaranteed. When the XRT will be fully operational and in case SLAC observe that the temperature stability is not meet, SLAC will provide a specific enclosure around the monochromator to provide the device a suitable temperature environment to perform.
- Also the location of the XCS Large Offset Monochromator, 45 meters upstream the diffractometer location, is on the same concrete slab than the remaining part of all the XCS optical components located downstream the LO-monochromator. SLAC will provide during the design phase vibration measurements of the floor where the monochromator is expected to be installed and operated.

15. Motion Control Requirement:

15.1. Motor Specifications and Requirements:

Any motors external to the vacuum envelope shall be Intelligent Motion Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control.

Motors that are inside the vacuum envelope must be UHV vacuum compatible to eliminate deposition of out-gassed material on the crystals. The motor/actuator and controller selection and controls interface must be reviewed by the SLAC controls group to assure compatibility with the LUSI XCS instrument controls.

15.2. Position Transducer Requirements:

For motions driven externally to the vacuum envelope, translations and rotation axes requiring external encoding shall use hardware compatible with the requirements specified for closed loop-external connection for the Intelligent Motion Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control.

For motions driven inside the vacuum envelope, the transducers must be UHV vacuum compatible to eliminate deposition of out-gassed material on the crystals. The specific transducers and controllers selected must be reviewed by the SLAC controls group to assure compatibility with the LUSI XCS instrument controls. The motions may be driven closed loop or open loop.

15.3. Limit Switches:

All translation and rotation elements shall be provided with adjustable limit switches. Adjustability shall be provided such that the limit switch can be positioned to change state at the point of contact with the hard stop

16. Cable Management:

All cabling shall be located, configured and labeled to provide rapid disconnect and reconnection for maintenance purposes.

All power and data cabling shall be routed and strain relieved in a manner such that all translation directions and rotation axis can achieve full range capability, plus 10% of full range, without load on cable, connector or any of the crystal motion hardware.

17. Power and Data Cable Requirements / Interface:

17.1. Power Cabling Requirement / Interface:

Power cable gauge size shall be the maximum size applicable to the given motor frame. Power cabling shall be of sufficient length to terminate at DIN block.

17.2. Control Cabling Requirement / Interface:

Control cabling shall be consistent with the requirements and specifications of Intelligent Motion Systems, Inc. MDrive™ motion control version (MDI3CRL-XXX) “smart motors” using MDrive Plus™ and Expanded PLUS2™ Control.
Motor controller to serial port server shall use RS-422/485 protocol. Communications port connector at motor shall be 10-pin friction lock wire crimp (style RL)

18. Reviews

All systems hardware will be subjected to SLAC review and approval. Reviews will be conducted in accordance with SLAC document number AP-391-000-59: “Engineering Review Guidelines”. SLAC reserves to right to employ an internal (SLAC direct), external-independent, or mixed source review panel.

Particular review attention will be devoted to:

- Personnel access restriction methodology
- Emergency stop methodology / mechanisms
- Power failure provision – fault modes
- Electrical Safety including Lock-Out / Tag-Out
- Training mode functionality
- Maintenance mode functionality.

All electrical hardware must meet SLAC electrical safety standards.

19. Environmental Safety and Health Requirements

19.1. General Seismic Considerations

SLAC is situated in an active seismic zone. All hardware exceeding a weight of 300 Lbs. and / or mounted greater than 4 feet above the floor will be reviewed by a SLAC “citizen safety committee” for seismic loading resistance. Applicable loads and structural behavior will be evaluated for compliance to the 1997 version of the uniform building code and SLAC publication SLAC-I-720-0A24E-002: “Specification for Seismic Design of Buildings, Structures, Equipment, and Systems at the Stanford Linear Accelerator”.

20. Supplemental System Requirements:

Requirements, including the following topics, will be addressed in detail in subsequent procurement specifications and contracts.

i. Inspection, testing and acceptance
ii. Installation support services
iii. Training support services
iv. Maintenance procedures, schedules and assistance
v. Repair and overhaul services

20.1. Materials

All parts and materials for the device shall be new and compatible with the performance requirements of this specification. No part interfaces should result in galvanic corrosion for the life of the system.

No system, sub-system or part shall be reconditioned or remanufactured.

All applicable material safety data sheets (MSDS) shall be provided and stored in an accessible location.

20.2. Paint Color

All painted surfaces are to be painted purple, defined as federal standard 17100.