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Specifications of the Mirrors MI1 and MI2 (X04S-OP-MI1, MI2) for the Materials Science Beamline 4S

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Call for Tender:

Two Cooled, Cylindrically-Bendable, Flat Mirrors
including polishing, coating, thermal absorber plate, mechanisms for cooling, bending and positioning, optical measurements and finite-element simulations, vacuum chambers, support structures, packing and shipping

Contents

1. Project Overview

The Swiss Light Source (SLS) is a 2.4 GeV, 0.4 A electron storage ring, presently under construction at the Paul Scherrer Institute (PSI) in Villigen, Switzerland. In an initial phase, 5 beamlines will be realized, one of which is the Materials Science Beamline - on a short straight section (4 m, number 4s). At this beamline (see Drawings 30040.25.042 and 30040.25.041), a minigap wiggler (65 poles, maximum field 1.97 T) will provide a high flux of X-rays in the energy range 5 - 40 keV alternately to one of three experimental stations: computer microtomography (33 m from the source), high-resolution, rapid-turnaround powder diffraction (37 m) and in-situ surface diffraction (42 m). The diffraction experiments will use a double-crystal Si [111] monochromator (19.5 m from the source, first reflection downward) with sagittal focusing, and for microtomography operation, the crystals will be driven out of the beam producing a polychromatic “pink beam”. The accepted beam divergence will be 0.23 x 2.5 $mrad^2$.

Two key optical components are the bendable cylindrical mirrors in front of (17 m) and behind (21 m) the monochromator. The first mirror (MI1), reflecting upward, serves as a low-pass filter and to collimate the beam vertically, and the second (MI2) directs the beam in a horizontal direction and provides vertical focussing at any of the 3 experimental stations. Both mirrors are Rh-coated, with clear optical apertures of 55 x 800 mm^2. A key issue is the high power (^{2}1.2 kW) and peak power density (^{2}66 mW/mm^2) absorbed by MI1.

2. Summary

This specification applies to two flat, cylindrically-bendable mirrors MI1 and MI2, to be used for synchrotron radiation between 5 and 40 keV photon energy. The contractor is to grind, polish and coat the mirrors, construct mechanisms to provide suitable thermal absorption protection, mirror cooling, bending and positioning, perform optical measurements and finite-element simulations of the finished assembly, and provide suitable vacuum chambers and support structures. The first mirror, MI1, reflects upward, and the second, MI2, downward.

The clear aperture area of each mirror (optically active surface) is to be 55×800 mm^2. The contractor is to specify the proposed material and dimensions of the mirror substrates. The polished surface roughness of the mirrors after rhodium coating is to be 5 Å rms or less, and the longitudinal and sagittal slope deviations must not exceed 5 µrad rms and 50 µrad rms respectively, both in a flat state and with respect to the bent cylindrical reference surface.

During operation, the mirrors will absorb a high heat load. (The maximum peak power density and maximum total power absorbed by mirror MI1 are 66 mW/mm^2 and 1.2 kW, respectively. Detailed beam parameters are given in the specification.) Suitable cooling mechanisms are to be constructed for safely dissipating this heat. Water-cooled absorber plates shall be included in the design to protect the front surfaces of the mirrors from a misaligned incident photon beam.

The mirrors are to be dynamically bent to a cylindrical form, within the slope errors specified. The bending radii vary from 5 to 30 km. Suitable remote-controllable bending mechanisms are to be constructed for this purpose.

The mirrors are to be accurately inclined and positioned with respect to the synchrotron beam. The repeatability of the pitch angle and vertical position shall be 5 µrad and 5 µm, respectively. The total range of vertical movement of MI2 is 75 mm. Suitable remote-controllable positioning mechanisms, including encoders, are to be constructed for this purpose. The mirror, with its cooling, bending and positioning mechanisms, shall be supported independently of the vacuum chamber. The bending and cooling mechanisms are to be thermally shielded from the scattered X-rays, preferably by being situated behind the mirror substrate.

The optical quality of the mirrors, with the cooling and bending mechanisms attached and operational, must be demonstrated to the satisfaction of PSI by direct optical measurements in the flat state and at the minimum curvature radius. In addition, the contractor must, via numerical calculations, demonstrate to the satisfaction of PSI that the optical specifications of the mirror will be fulfilled under the maximum thermal load.

The mirrors will be used in high vacuum at 1×10^{-8} Torr. Vacuum chambers, which are compatible with the required cooling, bending and positioning, will be supplied by the contractor. Provision shall be made for attachment to auxiliary vacuum equipment supplied by PSI. Stable support structures are to be supplied by the contractor to hold the mirrors at the correct heights in the X-ray beam. The nominal height of the reflecting surfaces of MI1 and MI2 shall be 1400 mm, and the maximum flange-to-flange axial length of the vacuum chambers shall be no longer than 1450 mm. Provision shall be made to lift each entire assembly as a unit with an overhead crane.

The bidding contractor is requested to provide the following information:

- The proposed material and size of the mirror substrates
- Plans of the proposed cooling, bending and positioning mechanisms, including the type and capacity of the coolant chillers and the placement of motors and sensors
- Plans of the proposed vacuum vessels and support structures
- Proposed design, manufacturing, testing and delivery schedule

Tenderers are requested to comment upon the specification and are encouraged to make alternative proposals to PSI <u>in addition</u> to the quotation for the given specification.

3. Specifications

3.1 Mirror substrates

The material, shape and size of the mirror substrates are to be specified by the contractor and are subject to approval by PSI. The clear aperture area of each mirror (optically active surface) is 55×800 mm^2 (see Drawing 30040.26.044).

The mirror optical surface shall be coated by the contractor with 600 Å ± 100 Å of rhodium. A standard binder layer between the mirror substrate and the rhodium optical coating may be used. The clear aperture area of the mirror surface shall have a roughness after rhodium coating of 5 Å rms or less for spatial wavelengths ranging from 5 to 3,000 µm.

The longitudinal slope deviation from the nominal cylindrical surface shall not exceed 5 µrad rms for mirror deformation wavelengths ranging from 3 mm to the length of the clear aperture. The sagittal slope deviation from the nominal cylindrical surface shall not exceed 50 µrad rms for mirror deformation wavelengths ranging from 3 mm to the width of the clear aperture. As a goal (desired but not required), over the central region of dimensions 55×400 mm^2 (see Drawing 30040.26.044), the longitudinal slope deviation from the nominal cylindrical surface shall not exceed 2 µrad rms.

3.2. Anticipated thermal load

The critical photon energy of the photon source is 7.5 keV. The integrated power in the incoming beam (after photon collimator (0.23 x 2.5 $mrad^2$) and filters (0.25 mm diamond and 0.5 mm Be)) is 2.1 kW, and the maximum power density is 6.3 $kW/mrad^2$. The intensity profile of the incoming photon beam is approximately Gaussian, as shown in Fig. 1 and described in Table 1.

The mirror MI1, at a distance of 17.25 m from the source, will be exposed to the full 2.1 kW white beam. MI2, at a distance of 20.75 m from the source, will see either the reflected parallel beam from MI1 (“pink beam” mode) or a monochromated beam (double-crystal Si [111] monochromator with dE/E=0.014%). The mirror tilt angles (kept identical for the two mirrors) will be adjusted according to the desired photon energy, which will be in the range 5 to 40 keV. The thermal loads on the mirrors for various photon energy settings (mirror tilt angles) are summarized in Tables 2a and 2b.

The maximum thermal loads correspond to the 5 keV setting. In this case, the absorbed power densities into the surfaces of MI1 and MI2 are distributed with the peak densities and rms Gaussian widths given in Table 3. The term “vertical” in the Table denotes the direction along the mirror surface in the beam direction.

3.2 Mirror cooling

The contractor shall construct a cooling mechanism suitable for maintaining the optical performance (slope errors) of the mirrors in operation at full incoming X-ray intensity and at the maximum inclination angle (5 mrad) within the specifications.

Each mirror is to be outfitted with a water-cooled “protection plate” situated in front of the upstream surface of the mirror substrate (see Drawing 30040.26.044). The edge of the plate shall be accurately aligned with the mirror surface, and the plate and the mirror shall move as a unit, but not be in physical contact.

Provision shall be made to monitor the temperature of the mirrors and of the absorber plates using standard thermocouples.

The contractor shall specify the number, type and capacity of the coolant chillers to be used to cool the mirrors and protection plates. The maximum coolant flow shall not exceed 3 m/s.

3.3 Mirror bending

Each mirror is to be dynamically bent using a mechanism to be constructed by the contractor. The deviation from a cylindrical shape is to be kept within the specified maximum slope error. The required curvature radii are given as a function of photon energy setting (tilt angle) in Table 4. The repeatability of the curvature radius shall be 1% with a resolution of 0.2%.

The bending radius shall be remote-controllable, and, if necessary, a suitable remote sensor shall be provided. The bending mechanism is to be protected from heating by scattered X-radiation, preferably by being located behind the mirror substrate. Any electronics, sensors, end-switches, motors or wiring associated with the bending mechanism shall either be UHV and radiation compatible or be located outside of the vacuum chamber.

3.4 Mirror positioning

Each mirror is to be mounted on a mechanism which permits it to be accurately positioned with respect to the incoming X-ray beam. The mirror positioning mechanism shall be supported independently from the vacuum chamber.

The degrees of freedom required, together with their ranges and repeatability are given in Table 5. These motions shall be remotely-controllable. The pitch angle and vertical position coordinates of each mirror are to be outfitted with encoders or inclinometers. Note that the total range of vertical movement for MI2 is 75 mm.

The positioning mechanism is to be protected from heating by scattered X-radiation, preferably by being located behind the mirror substrate or outside of the vacuum vessel. Any electronics, encoders, end-switches, motors or wiring associated with the positioning mechanism shall either be UHV and radiation compatible or be located outside of the vacuum chamber.

3.5 Mirror specification verification

The contractor shall demonstrate compliance with the roughness specification of Sec. 3.1 through roughness measurements conducted at a minimum of 10 uniformly distributed locations on the clear aperture. Acceptable instruments for the measurement of surface roughness for roughness wavelengths specified in Sec. 3.1 are the Wyko NCP 1000 or equivalent. Note that if such instruments are used, a 2.5× or similar objective is needed to cover the spatial frequency specifications. The quantitative results of these measurements and analysis shall be provided to PSI.

The contractor shall demonstrate compliance with the figure error specification in Sec. 3.1 with figure error measurements of the mirror. Figure error measurements shall be conducted along 3 uniformly distributed lines (at the center and sides of the clear aperture) in the longitudinal direction. The mirror shall be supported at its operational attachment points during the figure error measurement. The mirror shall be oriented with the polished surface horizontal for measurement, with the cooling and bending mechanisms attached and active (maximum fluid flow through the cooling mechanism and thermal protection plates, minimum and maximum radii of curvature imposed). Mirror MI1 shall reflect upwards during testing, MI2 downwards. The quantitative results of these measurements and analysis shall be provided to PSI.

Finite-element simulations shall be performed, and the models and results provided to PSI, demonstrating compliance with the figure error limits of the mirrors under the full operational thermal loads given in Sec. 3.2. A complete description of the numerical model used and the results obtained shall be provided to PSI.

As part of the final optical testing, the contractor shall provide PSI with calibration curves relating bending actuator settings and sensor readings with the actual mirror curvature radii. Furthermore, interferometric measurements (with e.g. a HP 5529A Dynamic Calibration System, available from PSI), using a dummy mirror with suitable reflecting elements, shall be made of the resolution and repeatability of the inclination and translation positioning. The contractor shall fabricate a suitable dummy mirror substrate, e.g. made of steel, for these measurements.

3.6 Mirror vacuum chambers and supports

An enclosing vacuum chamber suitable to operate the mirror with attached mechanisms in a vacuum of 1×10^{-8} Torr shall be constructed and supplied by the contractor. Design and fabrication of the vessels shall conform to the document: “UHV Materials and Technologies for SLS Front End and Beamline” (SLS-TME-TA-1998-0014).

Each mirror vessel will be directly pumped by a 500 l/s ion pump (Varian VacIon Plus 500, supplied by PSI). Benchmark dimensions are given in Drawings 30040.26.042 and 30040.26.043. The vacuum flanges connecting the vacuum chambers to the up- and downstream components are CF100, and the connection to the ion pump is CF150. The beam-inlet flange should be rotatable and the beam-outlet flange fixed. Vacuum seals are to use metal O-rings. The O-ring grooves shall be designed such that the rings do not fall out upon disassembly.

Each mirror vessel shall have a CF40 port for pressure measurement (Balzers Compact FullRange Gauge PKR 260, supplied by PSI), located on the lower surface of the chamber or on the right side when viewed along the beam direction. An additional CF40 port with a right-angle valve (VAT series 54, supplied by PSI) is required on the left side of each chamber when viewed along the beam direction for roughing, dry-nitrogen venting and leak-testing. Suitable water and electrical feedthroughs shall be included (on the left side of the chambers) to permit the required cooling, controls and monitoring. Two inclined view ports, to permit optical inspection of the mirror surfaces, are to be included in the vacuum vessels (see Drawings 30040.26.042 and 30040.26.043).

Provision shall be made to lift the lids of the vacuum chambers with an overhead crane. The individual pieces of the vacuum chambers shall be permanently marked by the supplier to avoid confusion during disassembly and reassembly.

The finished vacuum chambers, with installed and functional cooling, bending and positioning mechanisms, shall be demonstrated by the contractor to be helium leak tight and to produce a vacuum better than 1×10^{-8} Torr.

The vacuum chambers shall be supported by suitable support structures provided by the contractor. If a lateral load of 300 N is applied, the supported components shall not move more than 0.1 mm. The structures shall be made of carbon steel. The support structures must be painted with at least one primer coat and one coat of high-grade paint (bright blue). Coarse manual adjustment of the vacuum chamber position transverse to the beam direction shall be provided (±20 mm horizontal and vertical).

The mirrors shall be supported and positioned independently of the vacuum chamber. It is suggested that each mirror support structure incorporate a massive cast concrete base, which will be provided upon request by PSI. The 500 l/s ion pumps shall also be supported by the support structures in a manner that allows the pumps to be removed without dismounting the mirror chambers. The mounted mirror system shall have no resonant frequency lower than 50 Hz.

4. Deliverables

4.1 Plans and schedules

To be provided to PSI within 3 weeks of placing the contract, for written approval:

- A time and manpower schedule of all activities covered by the contract and a complete set of manufacturing, cleaning and testing procedures
- The welding plan.
- The quality plan and quality schedule.

- A complete set of manufacturing, cleaning and testing procedures.

4.2 Inspection reports

To be provided to PSI as they become available and as a complete set in the form of a documentation file at the end of the contract:

- A report, giving quantitative results and raw data files, of the roughness measurements on the mirror substrates.
- A report, giving quantitative results and raw data files, of the figure error measurements on the mirror substrates, with cooling and bending mechanisms attached and operational and being supported at their operational attachment points.
- The results of finite-element calculations simulating the effect of the full thermal load on the mirror figure, including a complete description of the numerical model used.
- Measured calibration curves relating the bending actuator settings and sensor readings with the actual mirror curvature radii.
- Interferometric measurement results demonstrating compliance with the repeatability and resolution of the inclination and translation positioning systems.
- Vacuum test results of the mirror vessels.

4.3 Lists and procedures

- The procedures for system assembly, disassembly and maintenance.
- A list of all tools and jigs required during the assembly, testing and alignment of MI1 and MI2. These tools and jigs will later be available free of charge to PSI.
- A list of all drawings used in the manufacture, assembly, testing and alignment of MI1 and MI2. The drawings will remain in the possession of the contractor, but, upon request, they will be made available free of charge to PSI to facilitate repairs or modifications. PSI guarantees that information from the drawings will not be given to any third party without the written consent of the contractor.

4.4 The mirror systems MI1 and MI2

- The mirror systems as specified in Sec. 3 of this specification.

5. Standardization

5.1 Vacuum components

Design and fabrication of the vessels shall conform to the document: “UHV Materials and Technologies for SLS Front End and Beamline” (SLS-TME-TA-1998-0014).

All the flanges and the gaskets must be Conflat (CF) type.

Vacuum chambers and pipes must be made of stainless steel AISI 304L, the flanges must be made of AISI 316LN-ESR, and the gaskets must be made of OFHC copper. The manufacturer must be approved by PSI.

Standard stainless steel bolts used for the final flange assembly shall be A4-80 Class, according to the UNI 7323 or similar standard; hexagon screw heads are requested for these bolts. All the bolts must be silver-plated, according to UNI ISO 4521.

No brazed joint shall separate a water-filled channel from a vacuum environment.

5.2 Stepping motors, sensors, end-switches and thermocouples

All stepping motors, encoders, cables and electronics must either be situated outside of the vacuum chambers or be compatible with a high radiation and an ultra-high vacuum environment.

Any stepping motors used to bend, tilt or translate the mirrors shall be controllable via a commercially-available VME card. Any strain gauges or other sensors included in the design shall likewise be readable via commercially-available VME cards.

All the end-switches must be bakeable, mechanical types; PSI suggests to use the products of Caburn UHV, Lewes, UK: model VH5LR for external use and model VH3 for internal use.

All the thermocouples are of the K-type. PSI will supply them with a diameter of 1 mm.

5.3 Contaminants and cleaning for high-vacuum service

All mirror, binder layer, and optical coating materials shall be high-vacuum compatible. High-vacuum compatibility is also required of the materials, coatings, bearings and lubricants of the cooling, bending and positioning mechanisms within the vacuum vessels. Any operation during the fabrication of the mirror which results in contaminants becoming embedded in the mirror or mirror coating is not acceptable. No materials may be used in the fabrication of the mirror which result in residual contamination after standard high-vacuum cleaning procedures. All holes and grooves in the mirror substrate shall be effectively blocked during polishing to avoid collecting possible contaminants.

The delivered mirror is to be clean and ready for use in a high-vacuum environment for qualification without beam at 1×10^{-8} Torr.

6. Quality assurance requirements

PSI prefers that manufacturers are registered to comply with ISO 9001 or an equivalent national standard. The requirements of PSI for quality assurance are stipulated in the specification ESRF/ENG/89/02 "Quality assurance requirements".

Control visits by PSI representatives must be possible, as described in the supply contract. In addition, a mandatory control will be carried out at the following points:

- during mirror substrate roughness measurements
- during mirror figure error measurements
- during bending radius calibration and positioning resolution and repeatability measurements
- before the final assembly

In order to schedule such inspections, it is required that PSI receive announcements of such events with two weeks advance notice.

PSI reserves the right to visit the contractor, upon reasonable prior notice, to review progress of the manufacturing process.

The contractor shall notify PSI immediately for review and approval of any design changes, fabrication discrepancies, changes in documented schedules or other commitments according to this specification and all terms of the purchase order.

7. Packing and Shipping

The mirrors shall be shipped without their cooling, bending and positioning mechanisms attached. The contractor shall supply a suitable shipping container and holder that fits inside the shipping container to protect the mirrors from damage, dust, lint and chemical contamination during shipment. The cooling, bending and positioning mechanisms, as well as the vacuum vessels and support structures (minus any concrete blocks) shall be packed and shipped separately from the mirrors.

Upon arrival at PSI, it is the responsibility of the contractor to mount the cooling, bending and positioning mechanisms on site and to mount the complete assemblies into the vacuum vessels.

The contractor is responsible for the safe delivery of the mirror systems F.O.B. PSI. The shipping address is:

Swiss Light Source
Paul Scherrer Institute
CH-5232 Villigen PSI
Attention: Prof. Bruce Patterson

Besides the shipping address, the following is to be displayed clearly on the outside of the packaging:

- the PSI contract number
- the weight of the loaded package
- support points for transport and lifting

9 List of Components Supplied by PSI

9.1 Components for inclusion in the mirror systems

- Varian VacIon Plus 500 l/s ion pump — 2 pieces
- Balzers PKR 260 DN40 Compact FullRange vacuum gauge — 2 pieces
- VAT series 54, DN40 CF right-angle valve — 2 pieces
- cast concrete bases for mirror support (if required) — 2 pieces
- K-type thermocouples — to be specified

9.2 Components for test purposes

- HP 5529A Dynamic Calibration System
- Varian ion pump controller
- stepping-motor controller
- encoder display

10. Drawings, Figures and Tables

10.1 List of attached drawings

- 30040.25.041 optics hutch (floor plan)
- 30040.25.042 beamline overview (side view)
- 30040.26.042 MI1 vacuum chamber
- 30040.26.043 MI2 vacuum chamber
- 30040.26.044 mirror detail

10.2 Figure

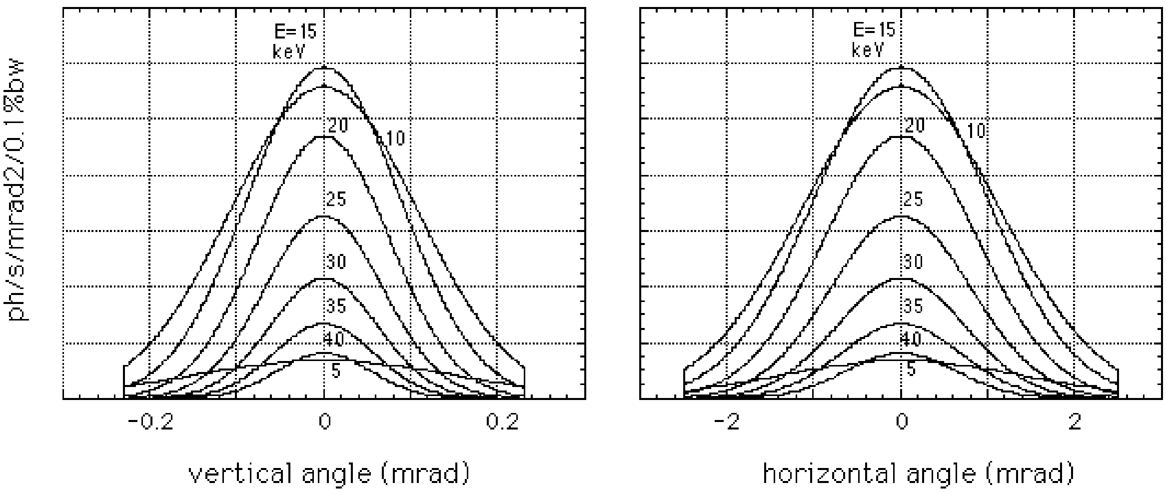

Figure 1. Vertical and horizontal profiles of the incoming photon flux density (after the collimator, carbon filter and beryllium window).

10.3 Tables

E (keV)	peak flux density (ph/s/mrad^2/0.1%bw)	$\sigma_{vertical}$ (mrad)	$\sigma_{horizontal}$ (mrad)
5	0.136 x 10^{15}	0.1519	1.396
10	1.115 x 10^{15}	0.1072	1.140
15	1.192 x 10^{15}	0.0877	0.991
20	0.943 x 10^{15}	0.0757	0.885
25	0.660 x 10^{15}	0.0677	0.804
30	0.431 x 10^{15}	0.0617	0.736
35	0.269 x 10^{15}	0.0574	0.685
40	0.163 x 10^{15}	0.0536	0.634

Table 1: Energy-dependent incoming peak flux densities and rms Gaussian widths (after the carbon filter and beryllium window).

photon energy setting (keV)	mirror tilt angle (mrad)	peak absorbed power density into surface (mW/mm^2)	total absorbed power (kW)
5	4.96	66.1	1.18
10	4.93	65.4	1.17
15	3.72	33.8	0.65
20	3.05	19.3	0.38
25	2.04	5.8	0.12
30	1.77	3.6	0.07
35	1.57	2.3	0.05
40	1.42	1.6	0.04

Table 2a. MI1: energy-dependent mirror tilt angles and absorbed thermal loads.

photon energy setting (keV)	mirror tilt angle (mrad)	peak absorbed power density into surface (mW/mm^2)	total absorbed power (kW)
5	4.96	7.7	0.17
10	4.93	7.7	0.17
15	3.72	5.6	0.13
20	3.05	4.0	0.09
25	2.04	2.4	0.06
30	1.77	1.9	0.04
35	1.57	1.4	0.03
40	1.42	1.2	0.03

Table 2b. MI2: energy-dependent mirror tilt angles and absorbed thermal loads (in “pink beam” mode).

	peak absorbed power density (mW/mm^2)	$\sigma_{vertical}$ (mm)	$\sigma_{horizontal}$ (mm)	total absorbed power (kW)
MI1	66.1	262	15.0	1.2
MI2 (“pink beam” mode)	7.7	349	18.7	0.17

Table 3. Gaussian parameters for the absorbed power density into the surfaces of MI1 and MI2 at the 5 keV setting (maximum thermal load). The term “vertical” denotes the direction along the mirror surface in the beam direction.

photon energy setting (keV)	mirror tilt angle (mrad)	MI1 curvature radius (km)	MI2 curvature radius (min and max) (km)
5	4.96	7.0	4.9 - 8.6
10	4.93	7.0	5.0 - 8.6
15	3.72	9.3	6.6 - 11.4
20	3.05	11.3	8.0 - 13.9
25	2.04	17.0	12.0 - 20.9
30	1.77	19.5	13.8 - 23.4
35	1.57	21.9	15.6 - 27.0
40	1.42	24.3	17.2 - 29.9

Table 4. The required curvature radii of MI1 and MI2. The minimum and maximum values for MI2 correspond to a vertical focus at the microtomography and in-situ experimental stations, respectively.

	motion	range	repeatability	resolution
MI1	pitch	(-2, 8) mrad	0.005 mrad	0.002 mrad
	roll	(-50, +50) mrad	0.2 mrad	0.05 mrad
	vertical	(1390, 1405) mm from floor	0.005 mm	0.002 mm
MI2	pitch	(-2, 8) mrad	0.005 mrad	0.002 mrad
	roll	(-50, +50) mrad	0.2 mrad	0.05 mrad
	vertical	(1370, 1445) mm from floor	0.005 mm	0.002 mm

Table 5. The required motions of the two mirrors. **Note: The total range of vertical movement for MI2 is 75 mm.**