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Mirror Mounts Designed for the Advanced Photon Source SRI-CAT

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Abstract: Use of a mirror for beamlines at third-generation synchrotron radiation facilities, such as the Advanced Photon Source (APS) at Argonne National Laboratory, has many advantages. [Yun et al., Rev. Sci. Instrum. 67(9)(1996)CD-ROM] A mirror as a first optical component provides significant reduction in the beam peak heat flux and total power on the downstream monochromator and simplifies the bremsstrahlung shielding design for the beamline transport. It also allows us to have a system for multibeamline branching and switching. More generally, a mirror is used for beam focusing and/or low-pass filtering. Six different mirror mounts have been designed for the SRI-CAT beamlines. Four of them are designed as water-cooled mirrors for white or pink beam use, and the other two are for monochromatic beam use. Mirror mount designs, including vacuum vessel structure and precision supporting stages, are presented in this paper.

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1. INTRODUCTION

In the beamline design for the Synchrotron Radiation Instrumentation Collaborative Access Team (SRI-CAT) at the Advanced Photon Source (APS) Argonne National Laboratory, x-ray mirrors are widely used for beam focusing and/or low-pass filtering. As shown in Table 1, six different mirror mounts have been designed for the SRI-CAT beamlines.

TABLE 1. Mirror mounts designed for SRI-CAT beamlines

Mirror Mounts	Location	Beam Type	Reflection	Mirror Type
Y2-20	2-ID-A	Undulator White Beam	Horizontal	Water-cooled silicon flat with multiple coating strips
Y4-20	2-ID-A	Undulator Pink Beam	Horizontal	Water-cooled silicon spherical with three mirrors switching
Y5-20	1-BM-A	BM White Beam	Vertical	Water-cooled silicon flat with commercial bender
Y3-20	2-BM-A	BM White Beam	Vertical	Water-cooled silicon flat multiple coating strips
Y3-30	2-BM-B	BM Pink or Mono Beam	Vertical	Water-cooled silicon flat
Y7-30	3-ID-B	Undulator Mono Beam	Vertical	Zerodur cylindrical with commercial bender

Use of mirrors for beamlines at synchrotron radiation facilities is a well-known technique,^{1,2,3} however, there are still many new challenging tasks in the design of the mirror mounts at third-generation synchrotron radiation facilities, such as the APS.

First, as the first optics on the beamline at the APS, the power density from the beam on the mirror is enormous. Six kW of the total emitted power with 160 W/mm² peak heat flux is generated at 30 m from the source when the undulator gap is closed.⁴ Thermal distortion control for the mirror optical surface therefore becomes a major task, and the mirror cooling system makes the mirror mount design very complicated.

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Second, the positioning precision and stability for the mirror mount design at the APS are critical, not only because the mirror usually is located at about 27 m or further from the source, but also because the high-brilliance synchrotron radiation source is in the 100 μm size. Microradian or even sub-microradian resolution is needed for the mirror mount primary angular motion control. Meanwhile, the dynamic characteristics of the mirror mount structure have to be analyzed to insure that the system is stable under the normal disturbance coming from the environment and cooling system.

Third, it is important to design a beam mask integrated with the mirror mount for missteered beam control to prevent component damage. For a multi-mirror system, especially for undulator beamline branching and switching, the design of such a masking system becomes a challenging task.

In this article, the modular mirror mounts designed for the SRI-CAT are presented. The mirror vacuum chamber, as well as its precise supporting and positioning system, is described. A multi-mirror system designed for the undulator beamlines branching and switching, including its beam masking system is also addressed.

2. MIRROR MOUNTS FOR A SINGLE MIRROR

A typical single mirror mount assembly is shown in Fig. 1. It consists of two main components: a vacuum chamber with in-vacuum kinematic mirror mounting structure and a modular support table, which performs the mirror primary positioning and angular adjustment functions by moving and/or rotating the whole mirror chamber.

FIGURE 1 Single mirror mount assembly Y3-20.

FIGURE 2 Top and side views of the Y3-30 chamber.

Mirror Chamber for SRI-CAT 2-BM-A (Y3-30)

The first mirror of SRI-CAT 2-BM beamline is located upstream of the double multilayer monochromator in the first optics enclosure. The main purpose of this mirror is to separate the synchrotron radiation from the bremsstrahlung. Thus, it greatly facilitates the transport of the pink beam into the end station. Deflecting the x-rays by 0.3° will create a separation of 3.3 cm between the x-rays and the primary Bremsstrahlung beam at the location of the integral shutters and stop. The separation provides sufficient clearance for placing a bremsstrahlung shield against the direct beam.

The mirror is a polished Si substrate with two coating stripes: a Pt coating for 33 keV high-energy cutoff and a Cr coating for 20 keV high-energy cutoff. The level of the high-energy cutoff can be selected by translating the mirror horizontally. The vertical acceptance is limited by the mirror size to 0.12 mrad for a 1.2-m long mirror. A simple side-cooling scheme is used to remove the heat load, which is possible because the peak heat flux is 0.0032 W/mm^2 on the mirror surface with a total power 125 Watts.

The Y3-30 mirror chamber has been designed to hold the first mirror with kinematic mounts inside vacuum chamber as shown in Fig. 2. To maximize the system stability, the vacuum chamber is designed such a way that both the supporting points (inside and outside of the vacuum chamber) are located on the same base and directly on the vacuum flanges. The kinematic mounts decouple the mirror from the vacuum chamber to avoid thermal and vacuum distortion, stresses resulting from changing of the environment. Three balls of the kinematic mount are located separately on top of two translation stages

with cross roller bearings. These two translation stages provide 60 mm horizontal movement. They are connected to a linear motorized actuator through a long plate. "S" shaped spring plates as shown in Fig. 3 clamp the bottom groove of the mirror to the kinematic mounts. Disk-style spring washers are used to minimize the clamping forces applied to the mirror.

The water cooling tube is silverbrazed to two pieces of an OFHC copper bar, which are clamped to two sides of the mirror. The entrance and exit ends of the copper tube are supported to minimize vibrations caused by the cooling water. Also two spring plungers hold the mirror at both ends to reduce the vibration of the mirror. Indium foils are placed between mirror and the copper cooling bar to increase the thermal conductivity of the interface.

Mirror Chamber for SRI-CAT 2-BM-B (Y3-20)

The Y3-20 mirror chamber for SRI-CAT 2-BM-B experimental station is similar to the Y3-30 mirror chamber in vacuum chamber design as well as in kinematic mounting and side cooling structures. However, the Y3-20 mirror has only one coating, and it does not move horizontally. In addition, the Y3-20 mirror chamber can be rotated in pitch from 0 – 1.5 degrees to select the appropriate spectral region for experiment needs.

FIGURE 3 Y3-30 mirror clamping details: (1) "s" shaped spring plate, (2) mirror, (3) disk spring washer.

FIGURE 4 Y5-20 mirror mounts at 1-BM-A

Mirror Chamber for SRI-CAT 1-BM-A (Y5-20)

As shown in Fig. 4, the first mirror for the SRICAT 1-BM beamline (Y5-20) is installed approximately 28 meter from the source upstream of a double-crystal monochromator in the first optics enclosure. This mirror enables the user to collimate the synchrotron beam vertically with the beam reflecting in an upward direction. Beam collimation is achieved through a pneumatic bending mechanism with a variable tangential radius of 15 km to infinite.

The material of the main mirror body is silicon with a 30 nm coating of palladium. This makes it possible for the mirror to act as a filter with a high-energy cutoff at 24 keV. With a total power of 320 W deposited on the mirror surface, moderate water cooling is required. A simple side-cooling scheme was chosen. The horizontal beam acceptance is limited by the width of the mirror to 3.7 mrad. Vertically the full beam can be accepted.

Other than the purpose and location of the access ports and feedthroughs, the design of the vacuum chamber, kinematic mount, and external kinematic support for this mirror is similar to the designs of the Y3-20 mirror mount system. While the chamber, mount, and support are designed at APS, the bending mechanism and the mirror body were developed and fabricated by the ZEISS company. This assembly is ultrahigh vacuum (UHV) compatible.

Mirror Chamber for SRI-CAT 3-ID-B (Y7-30)

The SRI-CAT 3-ID-B mirror allows the user to collimate or focus the synchrotron beam in both the vertical and horizontal directions, by providing two separate cylindrical grooves. This mirror is installed in the 3-ID-B hutch at

approximately 34 meters from the source. It is designed for use with monochromatic beam, which eliminates the need for water-cooling.

To achieve focal capabilities, a pneumatic bending mechanism with a variable tangential radius between 11 km and 33 km was chosen. The mirror reflects in the upward direction, which allows for the bending mechanism to operate in the vertical direction. The horizontal collimation and focusing is accomplished by the above mentioned two grooves in the mirror. Each groove can be moved into the beam as needed, utilizing three externally located horizontal stages that also kinematically support and align the entire mirror / housing assembly.

The material of the main mirror body is Zerodur. Both grooves are coated with > 30 nm palladium. Each groove is 800 mm long, which therefore allows for a maximum vertical acceptance of 2 mrad.

Except for additional access ports and feedthroughs, the design of the vacuum housing, kinematic mount, and external kinematic support for this mirror is similar to that for the Y3-20 mirror mount system. While the housing, mount, and support were designed at the APS, the bending mechanism and the mirror body were developed and fabricated by the ZEISS company. This assembly is UHV compatible.

Mirror Chamber for SRI-CAT 2-ID-A (Y2-20)

The first mirror mount for SRI-CAT 2-ID-A was designed for a 1200-mm-long water-cooled silicon mirror (Y2-20). On the horizontally deflecting mirror surface, three parallel stripes of different coating materials (Si, Pt, and Rh) provide various high-energy filtering functions. The UHV mirror chamber is set on a stepping-motor-driven kinematic mounting table, which has an 50 mm vertical motion range to translate the tank and, therefore move the different reflecting surfaces into the beam. The mirror deflects the incident undulator radiation by 0.3° . The deflected beam has a maximum cut-off energy of 33 keV, using the Pt coating for the 2-ID-D/E branch. The original design of the Y2-20 mirror contained an internal direct water cooling system. Due to a manufacturing difficulties with the internal cooling channel structure, an alternate side-cooling silicon mirror has been installed and is now operational shown in Fig. 5. Several papers have been published about both direct-cooling and side-cooling structure for this mirror.^{5,6}

FIGURE 5 Y2-20 mirror mounts at 2-ID-A.

FIGURE 6 Schematic of the "cone-v-flat" equivalent rolling kinematic mounting structure.

Modular Designed Support and Positioning Table for Single Mirror

A common feature of the SRI-CAT single mirror support is the use of modular and standardized components, which resulted in economic use of engineering effort and design. In addition, each support incorporates a "cone-v-flat" equivalent rolling kinematic mounting structure, which provides high positioning precision and high load capacity for stable and minimally constrained support.⁷

Fig. 6 shows a schematic of the "cone-v-flat" equivalent rolling kinematic mounting structure. The top frame is the mounting base for the mirror chamber, which is attached via three self-aligned ball bearings to three precision vertical positioning stages.⁸ Each vertical stage is mounted on top of a pair of orthogonal stacked horizontal stages/slides. Table 2 shows the support table specifications for the mirror mounts Y3-20, Y3-30, Y5-20, and Y7-30.

Similar to the support table described above, the Y2-20 support consists of a set of precision stages mounted on three steel columns that are filled with sand for enhanced thermal and vibration stability. To improve the angular positioning resolution for the horizontally deflecting mirror, the mirror chamber is attached to a rotation platform assembly. Horizontal rotational movement is performed with a differential stage actuator by pushing/pulling through a spring-preloaded spherical point contact. A $0.025 \mu\text{rad}$ resolution has been achieved in a $50 \mu\text{rad}$ horizontal rotation range with a 1000-kg load.⁹ The dynamic properties of this support system have been studied via theoretical and experimental techniques by Basdogan et al.¹⁰

Table 2. Y5-20, Y3-20, Y3-30, Y7-30 Mirror Support Specifications

Load capacity	1000 kg
Degrees of freedom	4
Vertical travel range	25 mm
Horizontal travel range	25 mm
Vertical motion resolution	$0.64 \mu\text{m}$
Vertical motion repeatability	$5 \mu\text{m}$
Horizontal motion resolution	$3.2 \mu\text{m}$
Horizontal motion repeatability	$10 \mu\text{m}$
Straightness of trajectory	$200 \mu\text{rad}/25\text{mm}$
Pitch angle resolution	$0.6 \mu\text{rad}$
Yaw angle resolution	$3.0 \mu\text{rad}$

3. MIRROR MOUNTS FOR MULTI-MIRROR SYSTEM (Y4-20)

Multi-Mirror System for SRI-CAT 2-ID Beamlines

The second mirror chamber at SRI-CAT 2-ID-A is a vacuum vessel for three mirrors that switch the beam into the 2-ID-B and 2-ID-C beamline branches horizontally as shown in Fig. 7.

FIGURE 7 Schematic of 2-ID beamline branches.

FIGURE 8 Y4-20 multi-mirror system at 2-ID-A.

The Y4-20-C mirror receives an incident beam that is reflected by Y2-20 and deflects it to 2-ID-C branch by an angle of 2.5° from the incident beam. The cutoff energy of Y4-20-C is 3 keV. To switch the beam into the 2-ID-B branch, the Y4-20-C mirror can be moved out of the beam. The Y4-20-B1 mirror then receives the beam reflected by Y2-20 and deflects it by 2.5° to the Y4-20-B2 mirror, which deflects the beam by another 2.5° . The 2-ID-B branch accepts the beam reflected by Y4-

20-B2. When all of the mirrors in the second mirror chamber (Y4-20) are moved out of the beam, the beam reflected by Y2-20 is delivered into the 2-ID-D/E branch.

Modularly Designed Mirror Support and Manipulator for 2-ID Multi-mirror System

A modular, UHV-compatible mirror support and manipulator system has been designed for the three mirrors in 2-ID Y4-20-B1, Y4-20-B2, and Y4-20-C, as shown in Fig. 8. There are three mirror-mount platforms inside the vacuum chamber. Each platform is attached via three self-aligned ball bearings to three vertical posts, which also function as vacuum feed-through components with welded bellows. Each vertical post is mounted on the top of a pair of orthogonal stacked horizontal stages/slides, then assembled on the precision vertical stage. Similar to the single mirror support table, this mirror manipulator is a "cone-v-flat" equivalent rolling kinematic mounting structure. To improve the system stiffness, an extra stiffener platform is attached via three self-aligned ball bearings to the base of the three vertical posts.

The water supply pipes for the mirror side-cooling structure are through the center hole of the manipulator post with a UHV mini-flange. No water-to-vacuum joints exist in this design. The specifications for this UHV mirror-mount actuator/stage system are shown in Table 2. The large vertical travel range of the manipulator allows users to move the mirror out of the beam or to choose a different coating strip on the mirror surface. The analysis of this high-precision UHV mirror manipulator for vibration stability has been presented previously.¹¹

Table 3. Y4-20 Mirror support specifications

Load capacity	227 kg
Degrees of freedom	5
Vertical travel range	60 mm
Horizontal travel range	12 mm
Vertical motion resolution	0.3 μm
Vertical motion repeatability	3 μm
Horizontal motion resolution	0.1 μm
Horizontal motion repeatability	1 μm
Straightness of Trajectory	10 $\mu\text{rad}/5\text{mm}$
Pitch angle resolution	0.33 μrad
Roll angle resolution	2.4 μrad
Yaw angle resolution	1.1 μrad

Beam Masking for 2-ID Multi-Mirror System

To perform as a "fail safe" system, the beamlines must be designed to handle accidental missteering of the beam by the mirror, as well as the source, which can result in component damage. This can be achieved by limiting the angular motion of the mirror in conjunction with a carefully designed masking system. Maximum missteered beam ray-tracing analysis is needed to determine the mirror and mask system operational safety margin.

A total of eight masks are used for the 2-ID-A area, including the white-beam slit and the front-end masks for beam missteering control. Three of them are white-beam masks, which are water cooled and constructed with an enhanced heat-transfer mechanism developed for the APS front-end components.¹²

To prevent damage to the downstream beam transport components from the beam missteered by the mirrors in the Y4-20 mirror chamber, a mask is placed in each of the beamline branches in the photon shutter tank. In the 2-ID-D/E branch, the water-cooled mask is made of copper. For branches 2-ID-B and 2-ID-C, the mask is made of a tungsten alloy with indirect water cooling, so that the mask also functions as a bremsstrahlung collimator. In addition, two water-cooled masks are mounted in the beamline split-tank to protect the wall of the tank between the branches.

4. CONCLUSION

This paper discusses the modular mirror mounts designed for the SRI-CAT beamlines at the APS. Five different single mirror mounts and a multi-mirror system are presented. The use of modular and standardized components resulted in economic use of engineering effort and design.

Presently, the mirror mounts Y2-20, Y3-20, Y5-20, and Y7-30 have been installed on the beamline and are operational. The initial laboratory tests show that the mirror mounts achieved the expected design specifications. The mirror mount Y3-30 and the multi-mirror system Y4-20 are fabricated and in final alignment and installation stage. The mirror performance test data will be published in separate papers later.

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