New Focusing Mirror System for 12-BM Beamline at Sector 12 Advanced Photon Source (APS)

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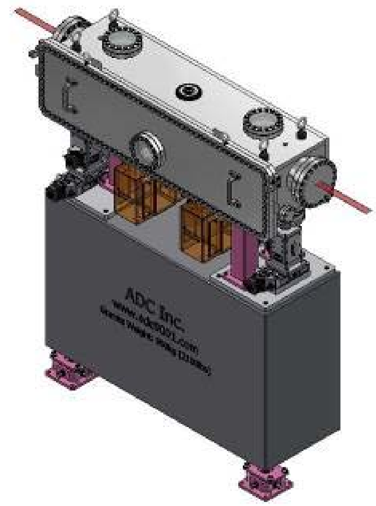
Abstract. The design of a new reflecting upward toroidal focusing mirror system for use in Advanced Photon Source (APS) synchrotron radiation 12BM at sector 12 beamline is described. This mirror system, contains Monolithic, Optical Grade, Single Crystal Silicon with overall dimensions of 1100 Length x 80 width x 50 Thick. The operating energy range is 5-28 KeV with 2 RMS tangential slope error. The bender provides a reproducible change in the radius between 8 and 30 km. It is constructed using UHV machining and cleaning practices, and bakeable to 120 °C.

12-BM is a multi-purpose beamline for spectroscopy (XAS), small angle scattering (SAXS) and surface scattering. The beamline is designed to provide a versatile platform to cover a wide range of experimental needs; XAS, SAXS/WAXS and Surface Scattering or combination of techniques on the samples under different experimental conditions (heating, cooling, in situ catalytic reaction conditions). In order to achieve an easily adjustable wavelength between 4.5 and 23 keV, the beamline uses a water-cooled, double-crystal, fixed-exit monochromator with Si(111) crystals.

TABLE 1. Bending Magnet Source Characteristics (nominal)

Source	**APS Bending Magnet**
Critical energy	19.51 keV
on-axis peak brilliance at 16.3 keV	2.9×10^{15} ph/sec/mrad^2/mm^2/0.1%bw
on-axis peak angular flux at 16.3 keV	9.6×10^{13} ph/sec/mrad^2/0.1%bw
on-axis peak horizontal angular flux at 5.6 keV	1.6×10^{13} ph/sec/mradh/0.1%bw
Monochromator type	Si (111)
Energy Range	4.5 keV - 23 keV
Resolution (ΔE/E)	1×10^{-4}
Flux (photos/sec)	2×10^{11} @ 12keV
Beam Size (focused HxV)	500µm × 1200µm

(a)



(b)

FIGURE 1. (a) and (b) APS 20-BM mirror system

INTRODUCTION

In this paper we will describe the design of an 1100 mm long silicon mirror system, shown in Figure 1, for Advanced Photon Source (APS). The APS 12-BM Beamline at Sector 12 mirror system consists of five primary subcomponents: The mirror optic itself, its positioning system, the bending mechanism, a vacuum chamber, and the support structure all provided as an integrated package. All subsystems were designed to provide the highest positional stability and structural rigidity with precision motions on all axes.

The 1100mm long silicon mirror substrate is ground from a single crystal boule and then polished by a specialist synchrotron mirror vendor with over 30 years of experience. To provide horizontal (sagittal) focusing of a wide bend magnet fan, the substrate is ground with a cylindrical recess in its reflecting surface. Gravity deforms the mirror substrate since it is supported only at its ends, so to compensate for the gravitational forces a series of light springs provide an upward force along the length of the mirror. Both finite element analysis and analytical calculations confirm the adequacy of this compensation scheme which reduces gravity induced deformations to less than 5% of the manufacturing slope errors.

Design Features

The bender mechanism is driven by linear stepper motors outside the vacuum space, again separated by a floating bellow. The actuator bends a pair of long leaf springs equally via a wiffle tree linkage. The leaf springs impart a pure bending moment to each end of the mirror via a pivoting clamp in the manner of Howells and Lunt [1]. The clamp holds the mirror at each end of its length but outside the optically active surface to avoid local distortions marring the beam quality.

The optical plate (via the bellows assembly) is positioned by the set of stacked linear (XYZ) motorized motion stages. Linear motions with resolutions of a few microns are achieved without micro-stepping or gear reduction. Sub-micron motions are achieved with either micro-stepping or gear reduction. Angular motions are achieved by the equal and opposite motions of pairs of linear stages. For example, pitch is produced by motions of a pair of linear slides separated by a distance roughly the length of the mirror baseplate.

The linear slides are ADC's high precision jacks and slides with stepper motors and gearboxes. The jacks and slides use precise crossed roller bearings for high load, off-axis stiffness, and longevity. Sub-micron positioning achieved with micro-stepping or gearboxes [2]. The resolution and repeatability of a 6 DOF mirror system is shown in the chart below. ADC typically uses Renishaw Tonic incremental or Resolute absolute linear encoders that provide 0.1 microns per count. The Renishaw encoders interface, whether incremental or BISS or SSI is compatible with many different motion controllers such as Delta-Tau, Galil, Parker, and Pro-Dex among others.

TABLE 2. Specifications

Motion*	Range	Resolution	Repeatability
X (Transverse to Beam)	50 mm	0.1 µm	± 0.5 µm
Y (Vertical)	50 mm	0.05 µm	± 0.5 µm
Z (Beam Direction)	50 mm	0.1 µm	± 0.5 µm
Pitch (Rot. About X)	100 mrad	0.05 µrad	± 0.5 µrad
Roll (Rot. About Z)	580 mrad	0.32 µrad	± 1.6 µrad
Yaw (Rot. About Y)	100 mrad	0.1 µrad	± 0.5 µrad

*Linear stages with 50:1 gearing used for motion specification; different gear ratios available to meet customer specifications. Angular displacement and resolution based on 1m distance between motion stacks.

Raw Slope and Height Profiles of the 1100 mm Long Cylindrical Mirror shown in Figure 3 and Slope and Height Error Profiles of the 1100 mm Long Cylindrical Mirror shown in figure 4 are from another identical mirror design done by ADC in an earlier installation at APS.

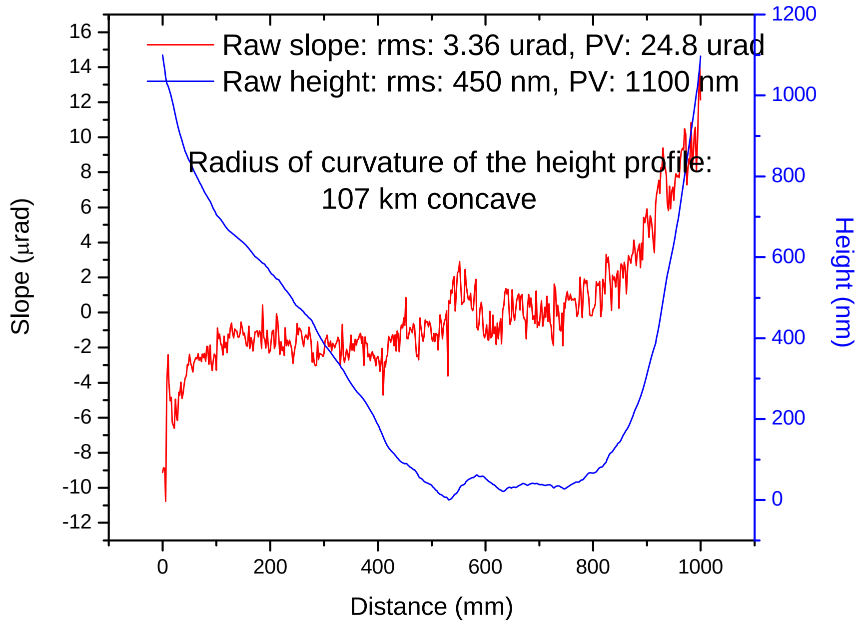


FIGURE 2. Raw Slope and Height Profiles of the 1100 mm Long Cylindrical Mirror

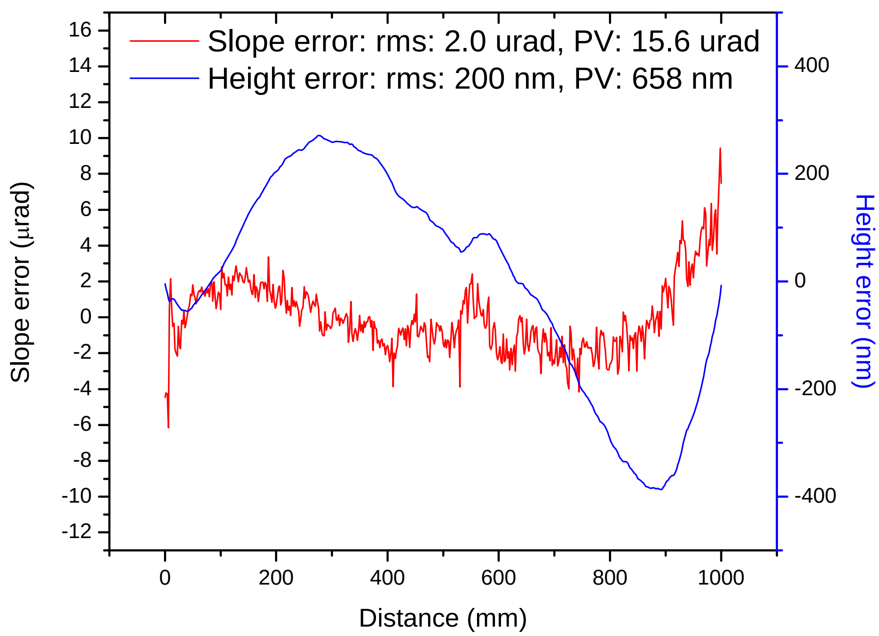
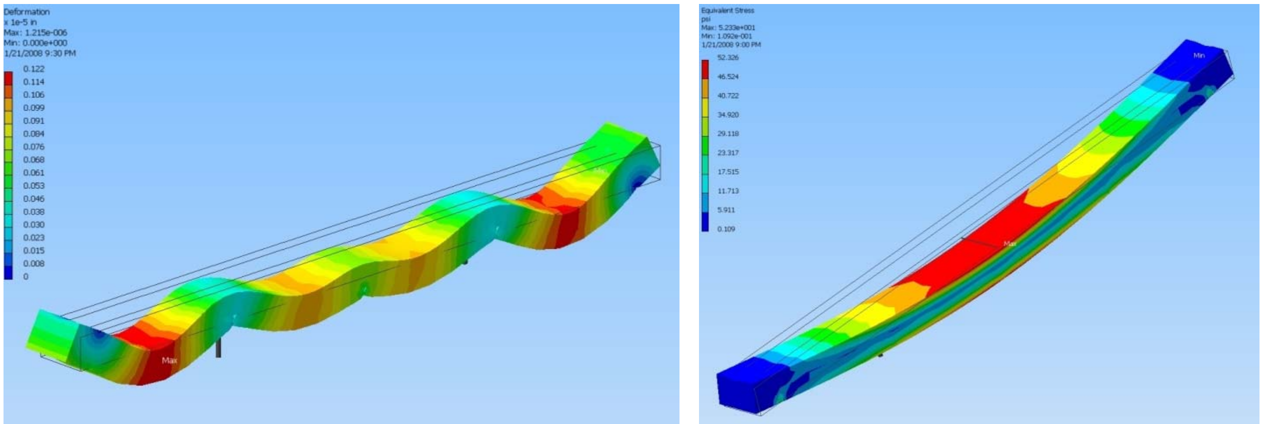


FIGURE 3. Slope and Height Error Profiles of the 1100 mm Long Cylindrical Mirror.
(After Subtracted the Best Linear Fit from the Raw Slope Profile)

The stainless steel vacuum chamber is robustly constructed with numerous ports for gauging and all the required instrumentation. A large ion pump mounted to the chamber provides pumping but with no chance of dust or contamination (from starting plasmas) reaching the mirror surface. The chamber can be roughly positioned independently from the granite base and mirror so that alignment to an existing beamline is simplified. A door the full size of side of the chamber allows easy access to the mirror for any internal operations. The door seal is by a knife edge like compression of a pure aluminum foil gasket ensuring leak tight UHV operation and ease of sealing compared to tricky wire seals. Viewports on the side and top of the chamber allow for quick inspection of the mirror surface and visual proof of the bender mechanism operation.

A massive natural granite plinth is used to support the mirror chamber and all the mirror motions. Granite damps floor vibrations before they can reach the mirror and beamline and is supported by a triplet of fully adjustable feet for coarse positioning. The granite base is mounted to the floor or base plate by adjustable feet shown at right. The feet allow for course adjustment of the mechanical system X, Y, and Z directions. Additional adjustments on the chamber support frame provide for a fine adjustment of the chamber. This allows for mating to existing vacuum chambers and beam pipes.

The maximum stresses in the mirror occur at the top (compressive) and bottom (tensile) faces. This was well under the minimum material limits (300 MPa) traditionally used for silicon optics. An ANSYS finite element model was used as a double check of this simple stress calculation, since the FEA model was required for later checking of the gravity sag compensation. The calculated maximum stress (58.7 psi) agrees well with the approximately 60 psi result from the FEA model. We do expect a slight discrepancy from analytic calculations since the cylindrical cut in the top surface of the mirror is precisely modeled in the FEA software, but not in our hand calculations. Figures 2a and 2b illustrate the stresses where Figures 3 and 4 illustrate the Slope and Height profiles.



(a) (b)

FIGURE 4. (a) Mirror Displacement with Gravity Compensation (b) Mirror Substrate Bending Stress

TABLE 3. Mirror Specifications

Property	Units	Specification
Type		Focusing
Direction		Reflecting Upward
Shape		Toroidal
Energy	KeV	5 - 28
Sagittal Radius	mm	63 +/-1
Material	Si	Monolithic, Optical Grade, Single Crystal Silicon
Useable Clear Aperture	mm	1000 Length x 40 Width
Overall Dimensions	mm	1100 Length x 80 width x 50 Thick
Polished Zone	mm	1100 Length x 60 mm Width
Sub Coating Material		Chromium (yes)
Sub Coating Thickness		100 Angstrom (5nm)
Coating Material		Platinum (Pt)
Coating Thickness		400 Angstrom (50nm)
Beam Incidence (Grazing) Angle	mrad	2.5
Maximum Absorbed Power	W	
Cooling		None
Bender Range	m	56.0 ± 1.5, Tangential Direction to Tune the Focal Length
Mirror Quality		
Tangential Slope Error	urad	2 RMS with >30KM curve removed on CA
Sagittal Slope Error	urad	20 RMS with curve removed
Roughness	Å	3 - 4 RMS. Measured at 11 locations and will be averaged using the RSS method to attain the mirror's qualified roughness. Measurements will be taken at the centerline of the mirror along the length.
Optical Distances		
source to white beam slit	m	22.97
source to collimating mirror	m	26
source to mono	m	27.33
source to focusing mirror	m	31
source to focal point	m	56.0 ± 1.5 (tunable)
Source Size and Divergence		
Horizontal	mm	30 (at White Beam Slits)
Vertical	mm	1 (at White Beam Slits)

CONCLUSIONS

ADC's design is based on leaf springs impart a pure bending moment to each end of the mirror via a pivoting clamp in the manner of Howells and Lunt. This is a proven design that ADC has used previously for similar x-ray mirror with excellent operation and stability history.

REFERENCES

1. Howells and Lunt, Optical Engineering, Aug. 1993
2. White Light Focusing Mirror; The Ninth International Conference on Synchrotron Radiation Instrumentation May 28 – June 2, 2006, DAEGU, EXCO, KOREA