X-Ray Optics System Options from ADC

ADC's standard mirror system consists of four primary subcomponents: the mirror optic, its positioning system, a vacuum chamber, and the support structure. Additional features ADC provides for mirror systems are bending mechanisms for the mirror optic and mirror cooling system for high heat load applications.

ADC is now offering customers two options for the positioning system of our mirrors: **stacked linear motion or a hexapod positioning** system. **Each system provides six degrees of freedom** for the mirror optic and is configured to meet the motion specifications of the user. There are advantages and disadvantages to using a linear motion system vs. a hexapod that need to be considered. Table 1 provides a description and comparison of key performance features for the stacked linear motion and hexapod mirror motion configurations.

Table 1. Comparison of features for stacked linear motion and hexapod mirror systems.

	Stacked Linear Motion	**Hexapod**
Cost	**Lower:** The system is comprised of several short-travel, ball-screw driven stages that are guided by precision crossed-roller bearings. This makes for a simple, but effective motion system	**High:** Precision bearing mounts and six precision linear actuators drive the motion of the platform. Complex controls and software are used to manipulate the platform.
Stiffness	**Good:** Bottom stage supports the weight of two stages above as well as the load from the mirror optics. Thus, the center of gravity for the payload on the bottom stage is located far above stage platform. Upper stages are not fixed to a rigid support	**Excellent:** Actuators work in parallel and see only axial loads. This provides the mirror optics with a very stiff support structure. The six actuators share the payload.
Motion Path	**Continuous Scanning:** Linear motion provides smooth scanning in the horizontal plane	**Intermittent Scanning:** Synchronous movement of the legs causes tip and tilt of the mirror optics platform. Smooth scanning is not possible.
Controls	**Simple:** Motions are controlled independently. Easy to debug the system and to physically measure position. Relationship between linear motion and angular displacement is simple.	**Complicated:** Each degree-of-freedom is co-dependent. Motion of the system is not as straight forward and it is difficult to determine source of position errors.
Accuracy	**Excellent:** Motions are performed by fewer actuators. This reduces the number of sources for positioning error to 2 or 3 linear actuators.	**Average:** Any motion is a result of motion from 6 actuators that each contribute to the overall position error of the mirror optic.

The sections that follow provide further description of the configurations and design of ADC's mirror systems. A detailed overview of mirror support structure, motion system configuration, and typical specifications of our mirror systems is discussed. ADC also provides mirror systems with bending mechanisms and cooling systems to meet the user's needs. A brief description and examples of these options are included.

Stacked Linear Motion

Our stacked linear motion mirror system consists of a single large vacuum chamber for the mirrors, with independent motion systems to each mirror. Figure 1 shows an example of ADC's standard design for a UHV mirror with stacked linear motions. All axis are motorized by the

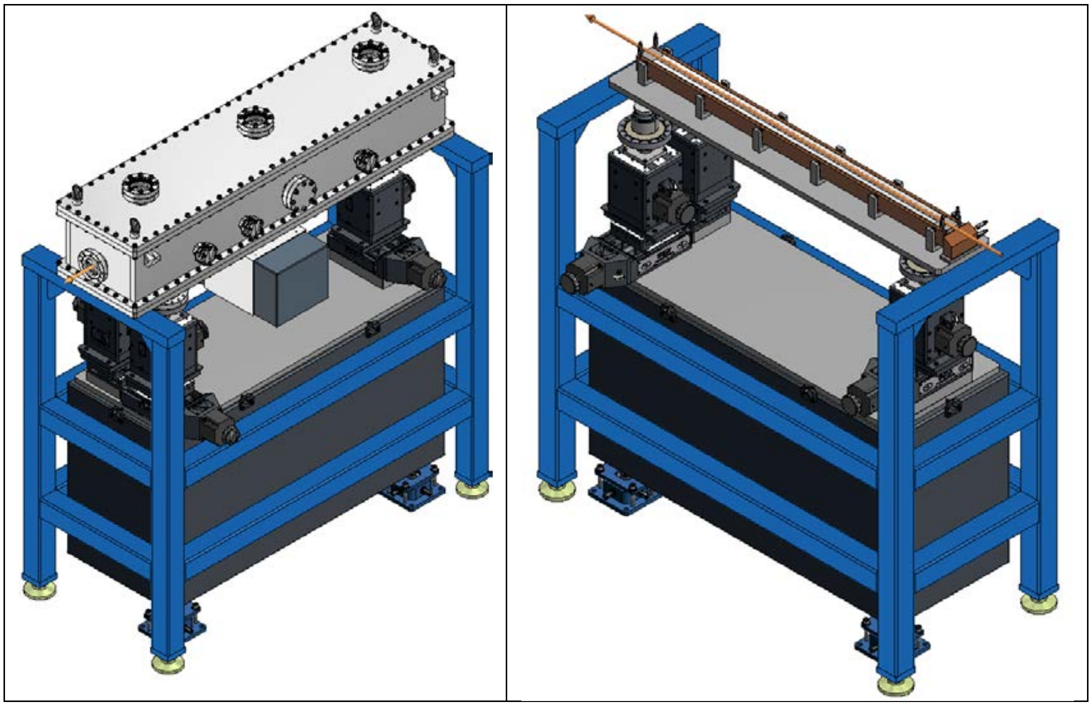

Figure 1. ADC Mirror System comprised of motorized stacked linear motions, granite plinth to support the motions, and UHV chamber mounted to steel framework. The steel frame is filled with sand to dampen floor vibrations. Kinematic feet below the granite plinth allow for adjustment of the mirror to its nominal position.

nature of the motions (for example the X stages work together to provide an X motion and in opposition to provide a yaw motion). The mirror optic is mounted to a base plate within the vacuum chamber. This base plate is supported kinematically and isolated from the vacuum chamber via a set of bellows that allow for motion of the three support posts. Figure 1 shows a cross-section of ADC's motion bellows assembly that is used to transfer motion from the out-of-vacuum linear stack to the mirror base plate. The base plate (via the bellows assembly) is positioned by the set of stacked linear (XYZ) motorized motion stages. Linear motions with resolutions of a few

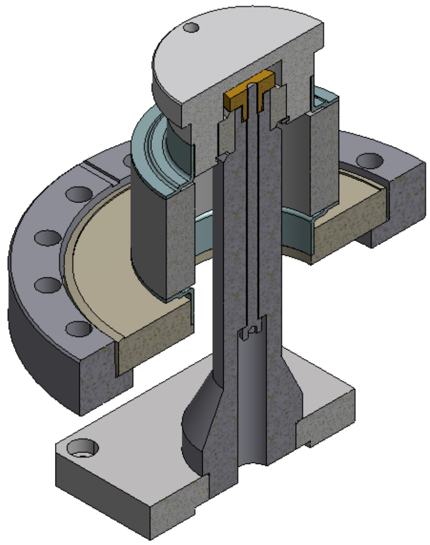

Figure 2. Cross-section view of ADC's motion bellows assembly. The bottom plate of the bellows is mounted to the linear motion stack, the flange mounts to the vacuum chamber, and the top of the assembly is connected to the mirror base plate.

microns are typically achieved without micro-stepping or gear reduction. Sub-micron motions are achieved with either microstepping or gear reduction. Table 1 shows typical motion specifications for a mirror with 50:1 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.

Table 2. Performance Specifications for a 6 DOF Stacked Linear Motion Mirror System

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 specifications; different gear ratios available to meet customer specifications. Angular displacement and resolution based on 1m distance between motion stacks.

The vacuum chamber is mounted rigidly to a steel frame that is filled with sand to dampen vibrations from the facility floor. A large granite plinth supports the motion systems. This provides a large mass to absorb floor vibrations and is a stable support for the mirror optics. The granite plinth is mounted to the floor by adjustable feet as used for our much more massive undulators. The feet allow for course adjustment of the motion system and mirror optic. Small adjustments on the chamber support frame provide for a fine adjustment of the chamber. This allows for mating up to existing vacuum chambers and beam pipes. The UHV mirror vessel is fabricated by one of the many experienced vendors in this field (Nor-Cal, MDC, Cryogenic & Vacuum Tech., Trinos, KJ Lesker, etc.) and assembled in our clean room environments.

Hexapod Motion System

The hexapod motion mirror system provides six degrees-of-freedom using six synchronously moving linear actuators. Figure 3 shows an example of ADC's design for a UHV mirror system with hexapod positioning. The hexapod motion system benefits from excellent stiffness of the axially loaded actuators. Each end of the linear actuators are mounted to granite platforms. The vacuum chamber and mirror assembly are mounted directly to the upper platform. Depending on the size of the mirror, the vacuum chamber can be mounted on a separate steel frame similar to our stacked linear motion mirror system. Translation and rotation come from the synchronous motion of the six actuators. Complex controls position the center of the platform and manipulate the platform to the desired pitch, roll, or yaw. Motion specifications for a hexapod mirror system are given in Table 3.

Figure 3. ADC Mirror System with a hexapod motion system. Linear actuators work together to provide six degrees-of-freedom for the optical surface. Both the mirror and UHV chamber are mounted directly to the platform. Other options, such as a separate steel frame to support the chamber are available.

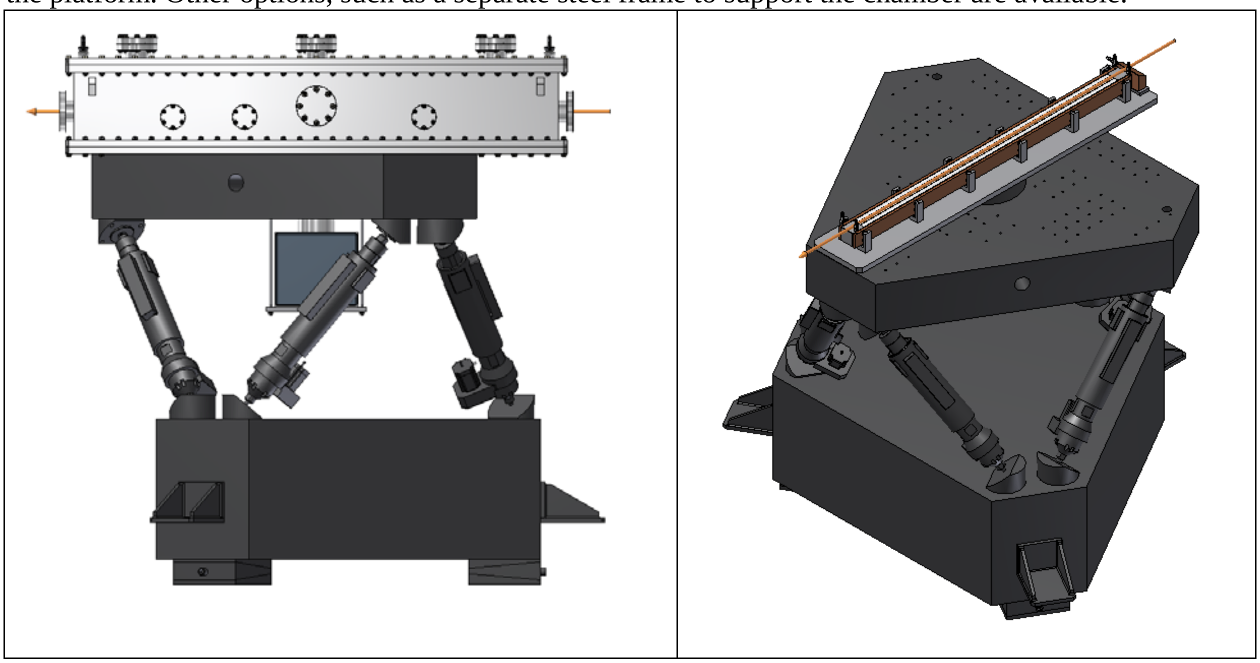

Table 3. Performance Specifications for a Hexapod Mirror Motion System

Motion	Range*	Resolution	Repeatability
X (Transverse to Beam)	130 mm	0.1 µm	± 0.5 µm
Y (Vertical)	100 mm	0.1 µm	± 0.5 µm
Z (Beam Direction)	130 mm	0.1 µm	± 0.5 µm
Pitch (Rot. About X)	105 mrad	0.5 µrad	± 2 µrad
Roll (Rot. About Z)	105 mrad	0.5 µrad	± 2 µrad
Yaw (Rot. About Y)	105 mrad	0.5 µrad	± 2 µrad

*Performances are specified for single axis motions, with all other axes at midrange, for a rotation center positioned at the center of the upper platform.

Additional Features and Components

It is common for mirror systems to require a bending mechanism to adjust the focus of the mirror. ADC has developed a very successful bending mechanism that was originally designed for APS 20-BM beamline. Shown in Figure 4, this bender is based on work by Malcolm Howells at ALS (Berkeley) and consists of a pivoting mirror clamp attached to both ends of the mirror and a pair of leaf springs mounted to the pivoting clamp. As a linear displacement is applied to the leaf springs (equally by a wiffle tree arrangement) a moment is imparted to both end clamps. Very fine control on the thickness of the leaf spring allows us to set the relationship between the linear actuator and the bend. The mirror system delivered to APS has performed for some years successfully.

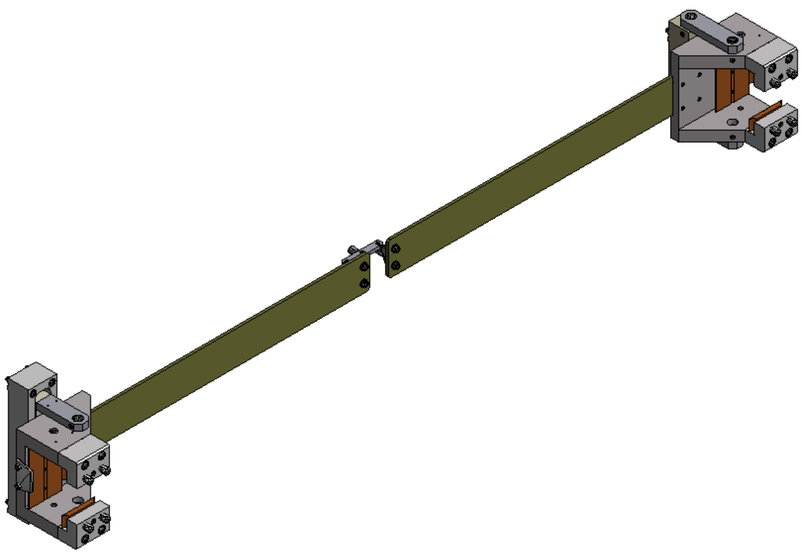

Figure 4. ADC's mirror bending mechanism. Each end of the mirror is held by pivoting clamps that are each attached to a leaf spring. Using a linear actuator and wiffle tree linkage, a displacement at the end of the leaf springs is used to impart a moment on each end clamp.

ADC also offers cooling systems to accommodate mirror systems subject to a high heat load. The design of the cooling system will depend on the amount of energy that must be absorbed. Typically, copper cooling plates placed on either side of the mirror substrate are used. Copper cooling masks on the upstream side of the substrate are provided as well. Cooling lines and plates are carefully designed to prevent transmission of vibration to the mirror substrate.

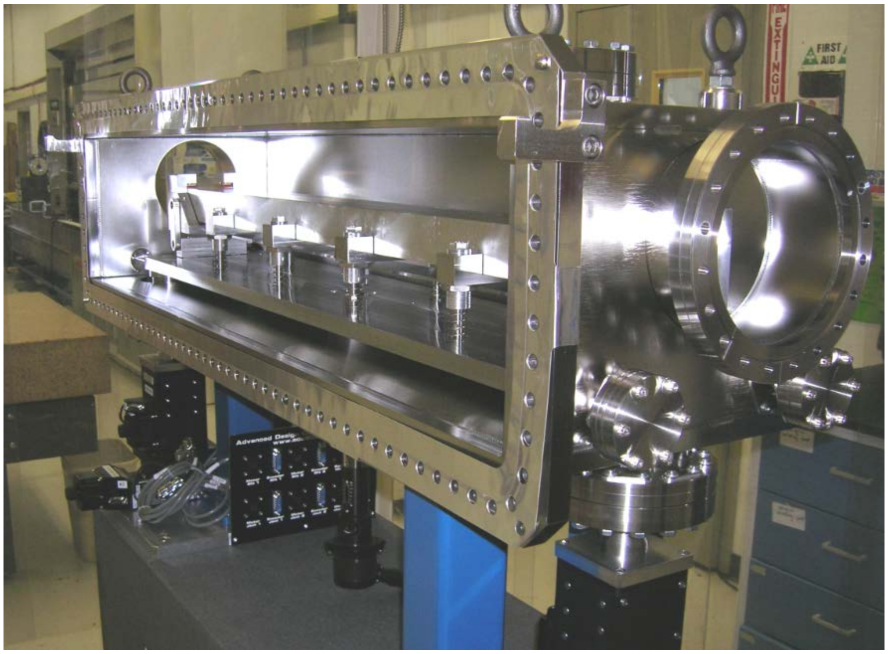

Figure 5. ADC vertical focusing mirror with bending mechanism, built for APS20-BM.

Metrology Laboratory

ADC has developed an optical profilometer for non-contact measurement of the flatness and bending of X-Ray focusing mirrors for synchrotron applications. This type of measurement requires sub-nanometer resolution and repeatability. The technology that can achieve these requirements measurement is based on spectral reflectance. Spectral reflectance is widely used in semi-conductor applications to measure the thickness of extremely thin films down to .1 nano-meters. In this application, the spectral reflectance's of different layers of semi-transparent thin films are compared to produce the thin film thickness measurement. In the profilometer application, the instrument simply returns the spectral response and the change in that response can be attributed to displacement of the mirror.

ADC has designed this system to minimize the external influences and maximize accuracy and repeatability. The Optics instrument is mounted to a granite gantry with extremely precise flatness and straightness of travel. Granite is also a very thermally stable material. The measurement length is 2 meters. The gantry is mounted to a granite base to reduce sensitivity to vibrations. The granite base rests on a 20 x 10 x 4 foot thick vibration isolation vault that is cut away from the building floor. The entire machine resides in a clean room with very tightly controlled temperature and humidity. Baffles cover the air conditioning ports to minimize air currents. The gantry profile is laser mapped so it can be subtracted from the spectral reflection.

With this measurement system ADC will be able to test synchrotron mirror systems up to 2 meters long and directly measure bending effects to sub-nanometer precision using non-contact, spectral reflectance methodology.