Mech. Eng. Design of Synchrotron Radiat. Equip. and Instrum. MEDSI2020, Chicago, IL, USA JACoW Publishing
ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-MOPC05

BEAMLINE ALIGNMENT AND CHARACTERIZATION WITH AN AUTOCOLLIMATOR*

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Abstract

An electronic autocollimator is a valuable tool that can assist in the alignment of optical beamline components such as mirrors and monochromators. It is also a powerful tool for *in situ* diagnoses of the mechanical behavior of such components. This can include the repeatability of crystals, gratings, and mirrors as they are rotated; the parasitic errors of these same optical elements as they are rotated and/or translated; and the repeatability and parasitic errors as bendable mirrors are actuated. The autocollimator can even be used to establish a secondary reference if such components require servicing. This paper will provide examples of such alignments, diagnoses, and references that have been made with an autocollimator on existing and recently commissioned beamlines at the Advanced Photon Source (APS). In addition, this paper will discuss how this experience influenced the specifications and subsequent designs of the new primary high-heat-load mirror systems (PHHLMS) that are currently under fabrication for six of the APS Upgrade (APS-U) feature beamlines. Each mirror was specified to provide *in situ* line-of-sight access for an autocollimator to either the center of the mirror's optical surface or to a smaller polished surface centered on the backside of each mirror substrate. This line of sight will be used for initial alignment of the mirror and will be available for *in situ* diagnoses if required in the future.

INTRODUCTION

Many strategies can be employed in the alignment of optical beamline components such as mirrors and monochromators. One can reference the actual optical surfaces with classical optical tooling (white face scale, jig transit, etc.) or get more sophisticated and use a portable coordinating measuring machine that relates the measured position of the optical surface to an external reference. A mirror or monochromator can then be installed onto a beamline using these predetermined external references and these techniques have been employed at the Advanced Photon Source (APS). An electronic autocollimator offers an additional means of establishing such alignments as it can measure the pitch and roll of the optical surface assuming an appropriate line of sight is available. A vertical leveling mirror (VLM) [1] is useful optical tool that can be used in concert with an autocollimator to establish an absolute angular reference relative to gravity. This is especially helpful in setting the roll of horizontally defecting mirrors and horizontally diffracting gratings and crystals. This paper begins with a discussion of how this technique was successfully used to align such a mirror system at the APS. This is followed by discussions of how an autocollimator was used to diagnose *in situ* the mechanical behavior of the motion systems on a couple of mirrors and one monochromator.

DUAL MIRROR SYSTEM AT 2-ID

The 2-ID beamline was converted from a colinear to a canted configuration [2] in late 2019. Part of that conversion involved installing two primary high-heat-load mirrors that share a common vacuum chamber into the upstream end of the first optical enclosure (FOE). The two mirrors increase the separation between the canted beams and focus these beams at slits located near the downstream end of the FOE. The upstream/inboard (us/in) mirror horizontally deflects the inboard canted beam outward. The downstream/outboard (ds/out) mirror horizontally deflects the outboard canted beam inward. The beams cross over each other about halfway along their path to their respective slits. The roll of these two mirrors was initially set using a jig transit lined up on the downstream end of each mirror. Each mirror was adjusted such that the top and bottom edges of each optical surface were aligned vertically. The holder and mechanism made it difficult to get a good line of sight to the mirror edges. Fortunately, the overall assembly was designed with an unobstructed line of sight to each optical surface. The process of setting up a VLM and auto-collimator was straightforward for the us/in mirror, which faces outward, but not as easy to implement for the ds/out mirror that faces inward. The setup for the ds/out mirror is complicated by its proximity to the inboard wall of the FOE. One can establish a line of sight to the mirror's optical surface using a VLM oriented at 45° to the mirror, but it is a two-stage process where the autocollimator is first leveled in roll by viewing the VLM straight on before rotating by 45°. The autocollimator indicated that the initial roll alignment on each mirror was in error by more than 1.0 mrad. The roll was eventually set to better than 100 µrad and could have been set more accurately if needed.

Work continued into early 2020 on converting the 2-ID beamline to a canted configuration. That work came to a halt when the APS went into minimum safe operations during the early stages of the COVID pandemic. During that time a water leak developed on the us/in mirror. The leak was confined to a single air guard bellows that surrounded the leaking cooling line and the leak did not compromise the vacuum integrity of the mirror system. Fortunately, the leak was discovered, and the water turned off in a timely fashion, but the repair did not start until a few months later once COVID protocols were put in place. The repair

* This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility at Argonne National Laboratory and is based on research supported by the U.S. DOE Office of Science-Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.
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required the removal of the vacuum chamber to access the internals. The existing position of the us/in mirror was documented prior to starting the repair. Survey and alignment documented the position of three of four extreme corners of the optical surface. An autocollimator was set up to measure the pitch and roll of the mirror. The autocollimator and VLM confirmed that the mirror's roll was very close to zero. A secondary reference mirror was then installed onto the vacuum chamber base flange and adjusted in pitch and roll such that the autocollimator read zero. A protective cover was placed around the reference mirror to prevent accidental bumping. This allowed the autocollimator to be removed during the actual leak repair. This is illustrated in Fig. 1.

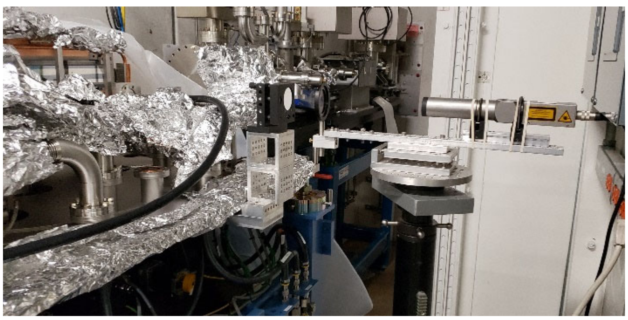

Figure 1: Autocollimator was aligned to us/in mirror at 2-ID prior to addition of reference mirror.

The repair was further complicated when water left over from the original leak migrated into one of the welded bellows that is part of the mirror support. In the end, that bellows had to be removed and UHV cleaned. The repair activities were performed without disturbing the reference mirror. The autocollimator was set up and aligned (zeroed) to the reference mirror once repairs were complete. The reference mirror was then removed from the line of sight to the us/in mirror and the autocollimator revealed that the mirror was essentially in the same position as before the repair. The survey and alignment check of the optical surface confirmed a similar result.

The 2-ID beamline in its canted configuration began taking beam in late 2020. An autocollimator was set up to monitor the mechanical behavior of each mirror. The results of such a test on the us/in mirror are shown in Fig. 2

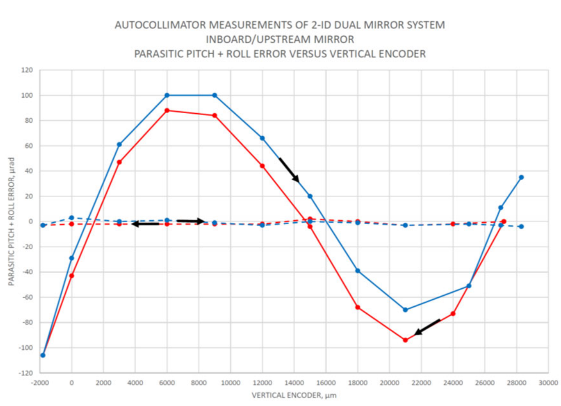

Figure 2: *In situ* autocollimator measurement of parasitic pitch and roll of the 2-ID us/in mirror.

where parasitic pitch and roll is plotted versus the full range of vertical stage travel. Similar tests were performed as part of the original factory acceptance testing (FAT), but these *in situ* tests are what really count as they are done as installed, under vacuum, and with cooling water flowing, and they can be repeated periodically to access whether the mechanical behavior has changed.

BENDABLE M5 MIRROR AT 4-ID XTIP

The 4-ID-XTIP branch beamline [3] was constructed in 2018-19 using the entrance slit, SGM, and exit slit that were part of the decommissioned 2-ID-B beamline. The exit slit has a long travel range to keep the slit at the grating focus as it is scanned in energy. That required that the final Kirkpatric-Baez mirrors on the new XTIP branch have a horizontally focusing bendable mirror. The original plan was to specify and procure a new elliptically bent M5 Mirror. In the end, the decision was made to repurpose a cylindrically bent mirror system that was originally the 011 4m-NIM M0 Mirror [4] at the Synchrotron Radiation Center (SRC). That mirror system had been back filled, sealed up, crated, and moved to the APS when the SRC facility shutdown. It sat in storage for several years until consideration was given to using it for XTIP. The mirror was coated with hard carbon and would have to be stripped and recoated. In addition, the original welded steel support frame would have to be replaced with a granite base and kinematic mounts to more easily position the mirror. Before that work was performed, a simple *in situ* autocollimator test (see photo in Fig. 3) was performed to verify that the mirror bending mechanism was still able to operate in a smooth and repeatable fashion despite its age and having been mothballed and crated for some years. The autocollimator was deliberately aligned ~ 50-mm upstream of the mirror pole such that it could detect a change in pitch at a point on the mirror as the bending mechanism was actuated. The data from that test is provided in Fig. 4 and shows that the bending mechanism was very smooth and repeatable but had some hysteresis which is typical of mirror benders in general. Additional autocollimator measurements were made while lined up on the mirror pole and that data demonstrated that the pitch remained near zero over the same range of bender actuation.

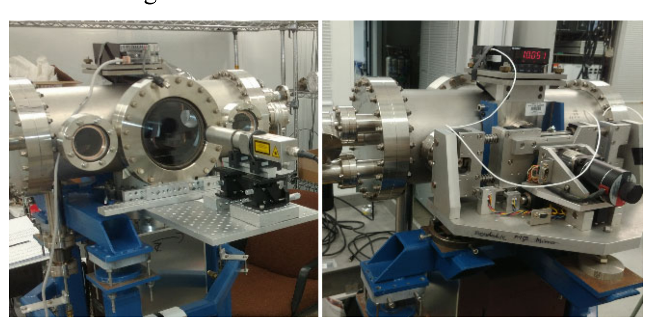

Figure 3: *In situ* autocollimator measurement of former SRC mirror prior to refurbishment for use as XTIP.

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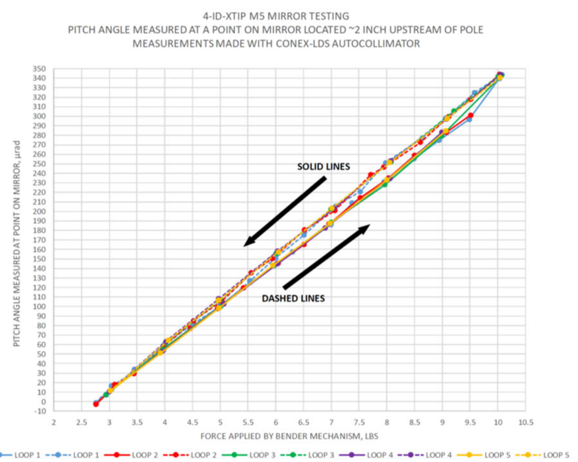

Figure 4: *In situ* autocollimator data of former SRC mirror prior to refurbishment for use at XTIP.

SGM SCAN DRIVE AT 4-ID-C

The SGM at 4-ID-C was procured in the mid-1990s. At that time most grating monochromators utilized linear encoders on an external sine drive that was calibrated to drive the energy scan. In later years, many monochromator designs adopted direct in-vacuum encoding of the scan axis rotation. A test was conducted with an autocollimator to see what improvement could be had if the SGM was retrofitted accordingly. An XPS measurement was made looking at the C 1s binding energy of HOPG, which has a sharp spectral feature. The autocollimator was aligned to the grating while set to an energy well above the binding energy. The SGM was then commanded to scan a large angular distance away and then return to the same energy according to the scan drive encoder. XPS measurements were repeatably made at this same energy reading according to the scan drive encoder. The graph in Fig. 5 shows a range of measured C1s binding energies that correlate linearly with the autocollimator reading. This data clearly shows that the scan drive encoder did not return the grating to the same position each time. Moreover, the correlation with the autocollimator indicated that the repeatability of the scan drive could be improved dramatically. This testing was prompted by construction of the 4-ID-XTIP, which utilizes an almost identical SGM for which such an upgrade was being considered. The test proved the retrofit could improve the energy calibration, but in the end neither SGM was upgraded due to the complexity of the retrofit.

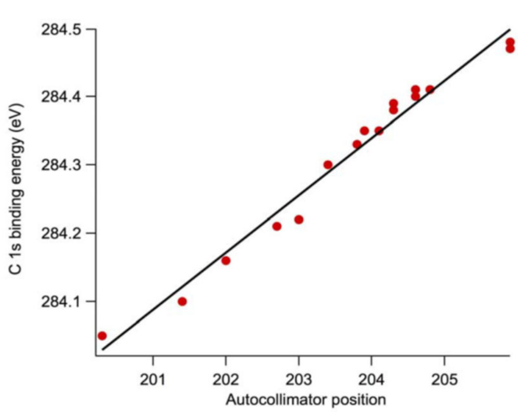

Figure 5: *In situ* autocollimator data from 4-ID-C SGM correlated with XPS measurements.

APS-U FEATURE BEAMLINE MIRRORS

The experiences gained at the APS from utilizing an autocollimator to align and diagnose the mechanical behavior of optical components drove the requirement that viewports, mounting hole patterns, and lines of sight be included on all the new primary high-heat-load mirror systems (PHHLMS) for six APS Upgrade (APS-U) feature beamlines. There are at total of 13 mirrors that make up these primary mirrors: five inward facing, five outward facing, two downward facing, and one upward facing. A direct line of sight from a viewport to the mirror's optical surface is ideal, but not very feasible on downward facing mirrors. In addition, it can be challenging to maintain lines of sight to the optical surface on the inward facing mirrors. In the end, a viewport and line of sight is still required for viewing the optical surface on all mirrors except for those that are downward facing. An additional requirement was made on inward and downward facing mirrors that a polished reference surface be centered on the backside of such mirrors and that corresponding lines of sight and viewports be provided for use with an autocollimator. These features will be used for initial alignment of the mirror and will be available for *in situ* diagnosing if required in the future.

CONCLUSIONS

An electronic autocollimator is a valuable tool for aligning beamline optical components and for *in situ* diagnoses of the mechanical behavior of such components. This has been a useful tool on many APS beamlines and that experience informed the specifications for the PHHLMS for APS-U feature beamlines.

ACKNOWLEDGEMENTS

The author acknowledges Fabricio Marin for his collection of the parasitic pitch and roll data presented in Fig. 2 and Richard Rosenberg for the correlation of XPS to autocollimator data presented in Fig. 5.

REFERENCES

[1] C. L. Farrand, "Vertical Leveling Mirror," U.S. Patent No. 2907246, Oct. 6, 1959.

[2] D. Capatina *et al.*, "APS 2-ID Beamline, Upgrade to Canted Configuration", in *Proc. 9th Mechanical Engineering Design of Synchrotron Radiation Equipment and Instrumentation Int. Conf. (MEDSI'16)*, Barcelona, Spain, Sep. 2016, pp. 342-344. doi:10.18429/JACoW-MEDSI2016-WEPE18

[3] V. Rose *et al.*, "XTIP – the world's first beamline dedicated to the synchrotron X-ray scanning tunneling microscopy technique," *J. Synchrotron Rad.*, vol. 27, pp. 836-843, 2020. doi:10.1107/S1600577520003689

[4] T. Kubala, M. Fisher, R. Reininger, M. Severson, "New actively bent plane mirror at SRC," *AIP Conference Proceedings 417*, p. 130, 1997. doi:10.1063/1.54610