MINIMIZING GRATING SLOPE ERRORS IN THE IEX MONOCHROMATOR AT THE ADVANCED PHOTON SOURCE

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Abstract

The IEX beamline at the APS is currently in the commissioning phase. The energy resolution of the beamline was not meeting original specifications by several orders of magnitude. The monochromator, an in-focus VLS-PGM, is currently configured with a high and a medium-line-density grating. Experimental results indicated that both gratings were contributing to the poor energy resolution and this led to venting the monochromator to investigate. The initial suspicion was that a systematic error had occurred in the ruling process on the VLS gratings, but that proved to not be the case. Instead the problem was isolated to mechanical constraints used to mount the gratings into their respective side-cooled holders. Modifications were made to the holders to eliminate problematic constraints without compromising the rest of the design. Metrology performed on the gratings in the original and modified holders demonstrated a 20-fold improvement in the surface profile error which was consistent with finite element analysis performed in support of the modifications. Two gratings were successfully reinstalled and subsequent measurements with beam show a dramatic improvement in energy resolution.

BEAMLINE

The Intermediate-Energy X-ray (IEX) beamline at the Advanced Photon Source (APS) at Argonne National Laboratory was designed with two separate branches, each with a dedicated endstation: one dedicated to angle-resolved photoemission spectroscopy (ARPES) and the other to resonant soft X-ray scattering (RSXS) [1]. The high energy resolution required by the ARPES endstation is achieved using an in-focus variable line spacing plane grating monochromator (VLS-PGM) [2]. To meet the demands of the two experimental techniques the monochromator is designed to house up to four water side-cooled gratings. It is currently configured with a high-line-density grating (HEG) with a nominal 2400 l/mm and a medium-line-density grating (MEG) with a nominal 1200 l/mm. The HEG is primarily for use with the ARPES branch when conducting higher resolution experiments. The MEG offers higher flux with moderate resolution that can be used by both the ARPES and RSXS branches. Future plans include a low-line-density grating (LEG) with a nominal 400 l/mm that is optimized for photon hungry RSXS experiments.

The diffracted beam downstream of the exit slit was observed to shift in energy depending on the size and position of either the synchrotron beam or the clean-up aperture located just downstream of the monochromator. As a result, the energy resolution was very poor except for the smallest aperture sizes.

GRATINGS

The cause of the poor energy resolution was eventually isolated to the gratings using photoemission measurements at the ARPES endstation. A systematic scanning of a vertical aperture just downstream of the monochromator (before the beam significantly disperses) revealed that the energy of the diffracted beam shifted at the exit slit as one selected different sections of the dispersing beam. This technique essentially allowed one to scan along the length of the grating. Both the HEG and the MEG showed similar energy shifts.

Ruling Line-Density

In order to fully investigate the gratings, the monochromator needed to be vented. The initial suspicion was that a systematic error had occurred in the ruling process on both gratings which had been holographically ruled by the same vendor. No metrology had been performed to verify the variable ruling line density on either grating.

In anticipation of the ruling density being the problem, a new mechanically ruled MEG was acquired. In parallel, plans were made to remove the existing MEG and measure its ruling density. Unfortunately, the long trace profilometer (LTP) at the APS was undergoing an upgrade; as a result, arrangements were made with the optics metrology group at the SOLEIL Synchrotron to measure the ruling density of the original MEG on their LTP. The measurements confirmed that the original MEG was properly ruled. In the meantime, the real problem with the gratings had been isolated to the grating holder itself.

Grating Substrate

The mechanical details of the grating holder were reviewed in preparation for mounting the new MEG. The grating substrate design adopted for the IEX monochromator has three horizontal through-holes to facilitate clamping of side cooling blocks and three vertical holes to facilitate bolting the grating to a support from below as illustrated in Figure 1. The grating substrates were originally specified and fabricated with extremely good surface profiles of better than 1nm RMS. Surface profile measurements were not made after the original MEG and HEG were ruled or after they were installed into their respective

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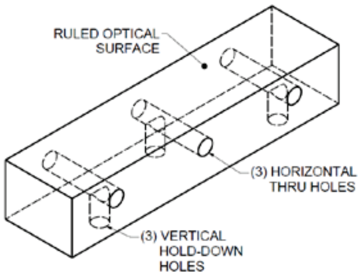

Figure 1: Grating Substrate Mounting Details.

holders. This is a lesson learned. Others have demonstrated the value in performing metrology at each step along the way to verify surface profile integrity [3, 4].

Original Grating Holder Design

A drawing of the original grating holder design is shown in Figure 2. The cooling blocks are clamped to the sides of the gratings with three custom bolts that pass through the gratings and are secured "finger tight" with a nut. These three custom bolts have tapped holes through their shanks that allow three vertical screws to pull the grating down against three steady rests. Each of the vertical screws are also torqued "finger tight". A review of this design revealed that the gratings were being subjected to bending moments as a result of the lever arms between the vertical hold-down screws and the steady rests. In addition, the use of screws that were torqued "finger tight" without any compliance were easy to overload. All of this had the potential to cause surface profile errors and led to a decision to modify the original grating holder.

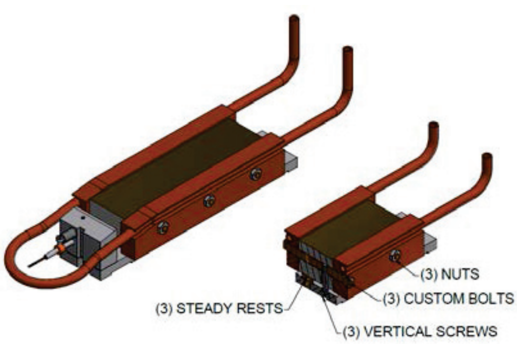

Figure 2: Original Grating Holder.

Modified Grating Holder Design

A drawing of the modified holder design is shown in Figure 3. The cooling blocks are still clamped to the sides of the grating with the same custom bolts, but a Belleville washer now resides beneath each of the nuts. The three steady rests have been eliminated and replaced with three spherical washers of the same height. The three spherical washers are located coaxial to the three vertical hold-down screws. A larger and deeper counterbored hole in the holder base plate allowed for the introduction of a stack of three Belleville washers at the head of a new low profile

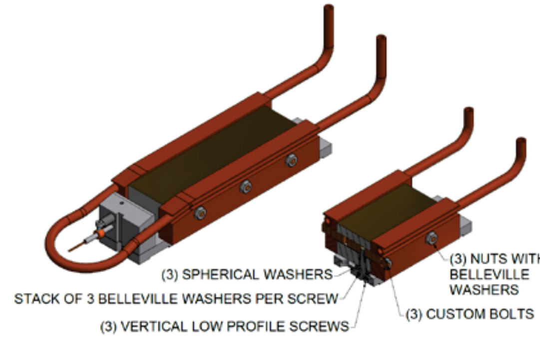

Figure 3: Modified Grating Holder.

vertical hold-down screw. The Belleville washers allow for the application of a repeatable, small clamping force that is thermally compliant.

FEA Modelling of Grating

Finite element analysis (FEA) was conducted on a model of the grating to verify that the proposed changes to the holder would be beneficial. Figure 4 compares the mechanical distortion of the grating by imposing constraints associated with the original and modified holders. A loading of 10N was assumed at each vertical screw on the original holder design. Contours of the resulting vertical displacement are displayed in mms. In order to achieve a similar distortion scale in the modified holder, it was required to apply a 1000N force to each of the corresponding screws. One can clearly see that potential surface profile errors are reduced significantly in the modified holder design.

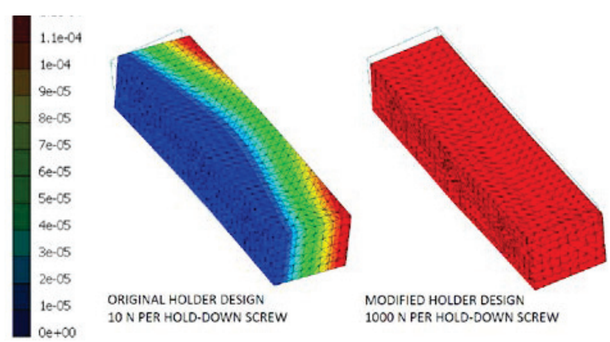

Figure 4: FEA Comparison of Grating Distortions.

Metrology

The plan was to perform surface profile measurements on the gratings in their original holders and to repeat these measurements with each grating unmounted and then remounted in the modified holder. With the LTP in the midst of an upgrade, another means of making such measurements was needed. An appropriate methodology was eventually developed using a Wyko 6000 Interferometer.

Surface profile measurements are much easier to make on a mirror than a grating, therefore a series of measurements were made by using a spare grating substrate. Measurements were made with the substrate unmounted,

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in the original holder and in the grating holder after it had been modified. The results of these measurements along the longitudinal centerline of the grating substrate are plotted in the upper and lower graphs of Figure 5. These results were consistent with the earlier FEA and confirmed that the original holder was inducing a significant surface error.

Similar measurements were also made with the Wyko on the actual gratings once the methodology had been perfected. Measurements on the MEG in its original holder before it was removed and sent to SOLEIL confirmed the presence of a large surface profile error which is also plotted in the upper graph of Figure 5. The original HEG and the new MEG were measured mounted in the modified holders before installing into the monochromator. The results of those measurements are summarized in the lower graph of Figure 5.

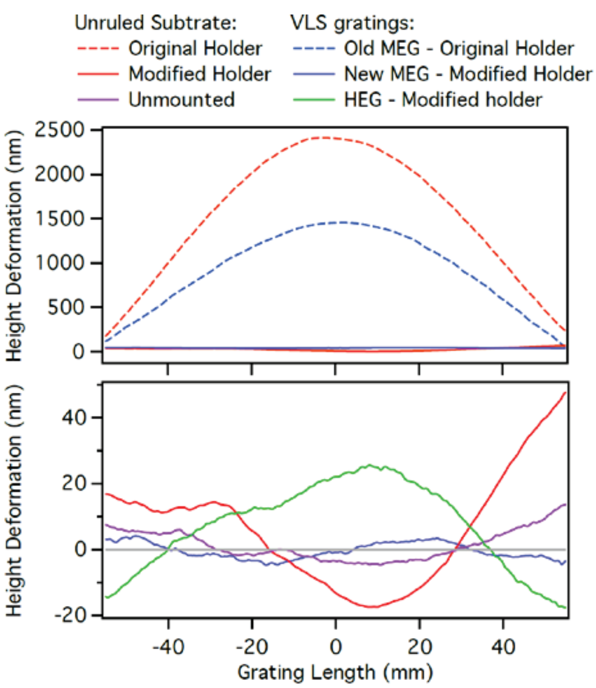

Figure 5: Surface Profile Measurements.

IMPROVED PERFORMANCE

With the original HEG and a new MEG mounted in modified holders and installed in the monochromator, commissioning of the monochromator resumed. The position of the horizontally deflecting M1 Mirror upstream of the monochromator was adjusted in roll to better center vertically the incoming beam on the monochromator. This was adjusted in response to another suspicious issue that had been corroborated during the removal of the gratings. The original MEG had developed a carbon contamination stripe that was only visible on the downstream half of the grating. This was consistent with the asymmetric plots that had been obtained when scanning a vertical aperture downstream of the monochromator to evaluate the shifts in energy before the monochromator was vented. The "before" plots in Figure 6 were made with the original MEG in the original holder and the "after" plots were made with the new MEG in the modified holder. They show a dramatic improvement in energy shift as one measures the energy of the Au 4f photoemission peaks and scans the vertical aperture downstream of the monochromator [5]. Similar results were also obtained for the HEG.

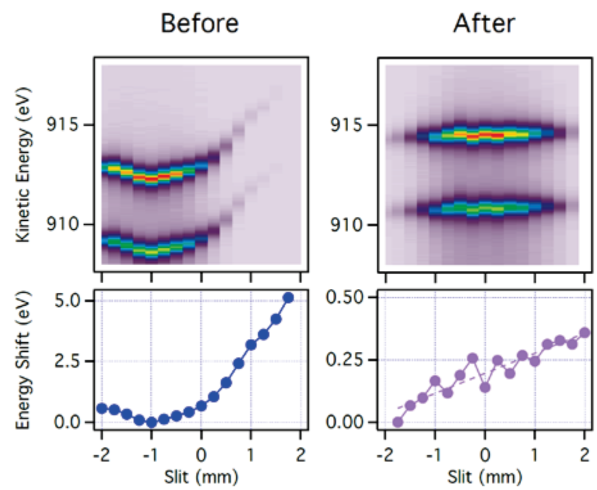

Figure 6: Photoemission Measurement Demonstrating Improved Energy Resolution.

CONCLUSIONS

Modifications to the grating holders in the monochromator at the IEX beamline significantly reduced surface profile errors in the grating thereby providing a dramatic improvement in the energy resolution of the beamline. Proper metrology of beamline optics at all stages of assembly cannot be over emphasized.

REFERENCES

[1] J. McChesney *et al.*, The Intermediate Energy X-ray beamline at the APS, Nuclear Instruments and Methods in Physics Research A 746 (2014) 98.

[2] R. Reininger, "The in-focus variable line spacing plane grating monochromator", Nuclear Instruments and Methods in Physics Research A 649 (2011) 139.

[3] F. Siewert *et al.*, "Inspection of a Spherical Triple VLS-grating for Self Seeding of FLASH at DESY, AIP Conf. Proc. 879 (2007) 667.

[4] J. Viefhaus *et al.*, "The Variable Polarization XUV beamline P04 at PETRA III: Optics, mechanics and their performance", Nuclear Instruments and Methods in Physics Research A 710 (2013) 151.

[5] F. Rodolakis *et al.*, "In-situ characterization of monochromators by energy-resolved imaging of both the incident and diffracted beam for a soft x-ray monochromator", unpublished.