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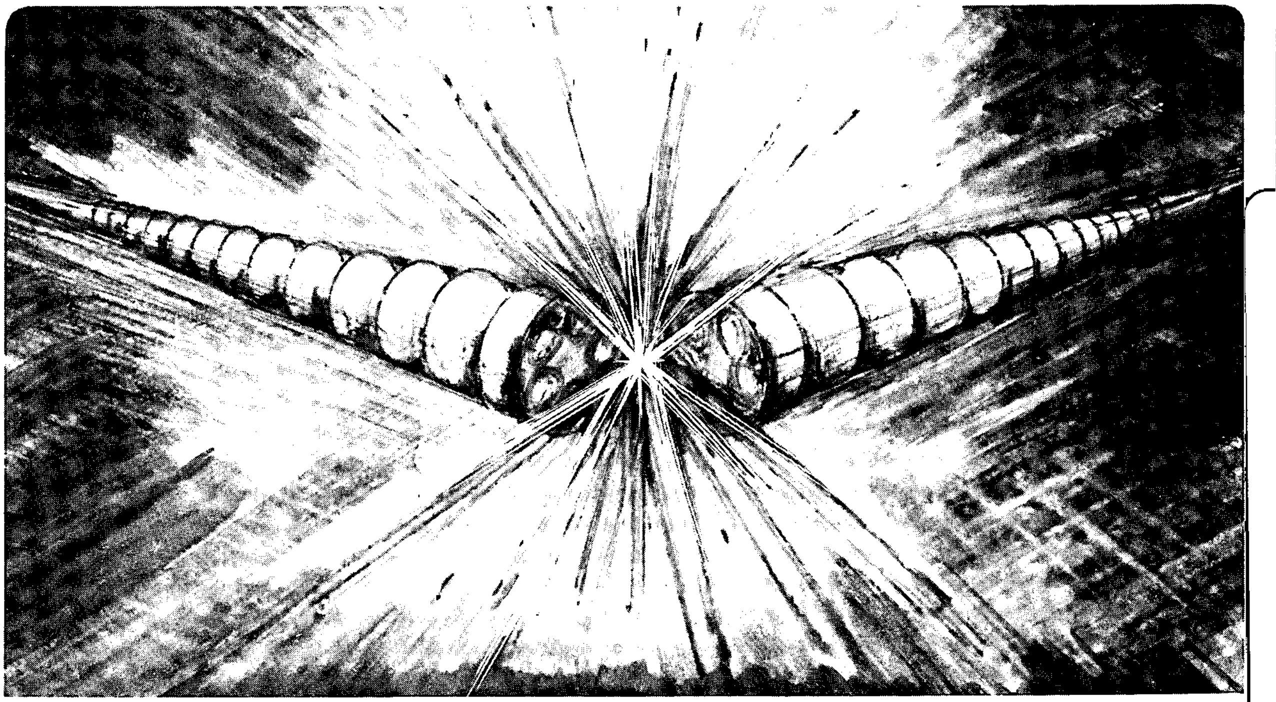

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XUV SYNCHROTRON OPTICAL COMPONENTS FOR THE ADVANCED LIGHT SOURCE: SUMMARY OF THE REQUIREMENTS AND THE DEVELOPMENTAL PROGRAM*

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XUV synchrotron optical components for the Advanced Light Source: Summary of the requirements and the developmental program

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Abstract

We give a brief summary of the requirements for water cooled optical components for the Advanced Light Source (ALS), a third generation synchrotron radiation source under construction at Lawrence Berkeley Laboratory (LBL). Materials choices, surface figure and smoothness specifications, and metrology systems for measuring the plated metal surfaces are discussed. Results from a finished water cooled copper alloy mirror will be used to demonstrate the state of the art in optical metrology with the Takacs Long Trace Profiler (LTP II).

2. Requirements

Many of the mirrors and grating substrates used in the past in synchrotron beamlines have been inferior. To cite what may or may not be a typical example, depending on how badly a particular research program may have suffered because of inferior optics, consider a toroidal mirror manufactured by standard optical polishing techniques for Beamline VI-1 at the Stanford Synchrotron Laboratory (SSRL). It was made by grinding the concave shape into fused silica. The toroid was then zone polished until it was about 5 Angstroms rms. In polishing the mirror this way the surface deviated considerably from the ideal figure. The mirror showed 20 arc second rms slope error deviation from best fit sphere as measured on the LTP at Brookhaven National Lab (BNL). When installed in the beamline it produced seven images of the synchrotron source on the entrance slit of the monochromator, greatly reducing the flux on the sample.

This was a typical example of the results of interaction between the customer and the vendor in that period. The customer typically did not realize the limitations that were involved in the manufacture of aspheric surfaces. Vendors often did not understand the uses for the optic, or the reasons that were behind the specifications. Neither the vendor nor the customer had the necessary metrology with which to confirm that the design specifications had been achieved.

For the ALS it was decided that the first undulator beamlines built with project funds would have all flat or spherical optical components, since spherical optics are in general easier to fabricate to high quality. This does not lead to large astigmatic images, since the distributed focusing scheme of Rense and Violett addresses this problem quite well.[1] This was implemented with the choice of the Spherical Grating Monochromator (SGM) for beamlines U5 and U8. This type of monochromator design has achieved good resolving power at several synchrotron radiation facilities.[2, 3, 4]

In order to achieve the necessary resolving power of approximately 10,000 these monochromator systems are about ten meters in length. Minimum slit widths of 10 microns are used with distances between the optical components of a few meters. These combine to produce total slope tolerances for the optics in the micro-radian range. For the ALS the allowed imaging defect is distributed approximately equally between the aberrations in the system, the heat load distortions, and the slope deviation from figuring errors in the optics. The following table briefly summarizes the specifications for the initial optics.

ALS Mirror and Grating Blank Specifications

Name	Size	radius	slope tolerance	micro roughness
U5M1	15"x3"	57.19m	1 μ-rad rms	6 Angstroms
U8M1	15"x3"	302.3m	5 μ-rad rms	6 Angstroms
U8M2	15"x3"	51.91m	0.8 μ-rad rms	6 Angstroms
U5G	8"x2.6"	70.0m	0.5 μ-rad rms	6 Angstroms
U8G	8"x2.6"	21.0m	0.5 μ-rad rms	6 Angstroms

The radii are held to ±1%, and when up to four optics are made at once, as is the case of the two grating blanks, the radii are much closer than the ±1% absolute tolerance. The micro roughness specification of 6 Angstroms rms is a number that evolved during the development. A survey of metal mirrors by Peter Takacs at BNL indicated that 10 Angstroms rms was a typical best surface micro roughness for metal mirrors.[5] As our development proceeded we were routinely achieving 6 Angstroms rms on electroless nickel substrates at the time that these specifications were finalized. Since then, one of us, (David Lunt) has improved the routinely attainable surface micro roughness considerably. The project did not calculate the scattering to support the specification, and the excellent micro-roughness obtained on the metal surfaces has justified this decision in retrospect. The slope tolerances are based mainly on geometrical considerations. Detailed diffraction calculations were not done to confirm this assumption. U8M1, a horizontally deflecting mirror, is specified with a greater slope error than the others since tangential slope errors on its surface will only move light parallel to the slits, and will not affect resolving power. The detailed design and specifications are given in several ALS beamline reports.[6, 7, 8]

The water cooling requirement led to the choice of Glidcop [9] for the mirror body, and electroless nickel as the polishable layer. This choice, which had to be made early in the project [10] was made because the brazing of silicon carbide, the other possible technology under study at the time, was viewed to not be sufficiently mature for consideration. The footprint of the radiation is calculated and cooling channels are added to the design to carry away the absorbed heat. This process is described in a paper given at this meeting by T. L. Swain and R. S. DiGennaro. [11]

The micro roughness is routinely measured with a micro profiler such as a WYKO TOPO, a ZYGO Maxim or a Micromap. We use an hybrid that uses the optics from an original WYKO NCP-1000 and electronics and software from Micromap.[12] For radius measurement we use a "radius bench" consisting of a precision flat, a collimating lens, and a Shack Interferometer. This system was manufactured by Tucson Optical Research Corp., Tucson, AZ 85719.

The measurement of the slope of the optics presented a considerably more difficult challenge. Classical interferometry is difficult or impossible on toroids, cylinders, ellipsoids, and even the shallow spheres that are in the table above. Point diffraction interferometry is difficult to implement routinely for toroids, and shallow spheres have just enough sag in general to swamp the data handling method with too many fringes when tested in systems using plane waves for the test wavefront. Even if a long radius lens is used to match the testing wavefront to the shallow spherical optic, the metrology problem has merely been shifted from the optic under test to the auxiliary lens.

After considerable study we chose the LTP system of Takacs at Brookhaven National Laboratory to measure the slope error.[13, 14, 15] Its many advantages include:

Parallel beams on the surface--no focusing necessary
Measures slope directly--only one integration to obtain height data
No auxiliary lenses or computer holograms necessary
Readily and inexpensively scalable to large sizes

We have constructed two profilers with improved features in collaboration with Takacs.[16, 17] These instruments were the result of a productive collaboration between the following national labs and industrial companies.

Manfred Grindel	Continental Optical	Contractor and Optical Fabrication
Niel Lien	Baker Manufacturing	Mechanical Design and Fabrication
David Lunt	Photon Sciences Intl.	Optical Systems Design
Peter Takacs	Brookhaven Natl. Lab.	Optical Systems Design
Wayne McKinney	Lawrence Berkeley Lab	Optical Systems Design
Steve Irick	Lawrence Berkeley Lab.	System Integration, and Software

It should be realized that the construction of two profilers is essential to the program. Having only one, and using it to do post-mortems on the optics after delivery does not improve the quality of the optics. Deploying the second instrument at the vendor so that they can check the optical components during manufacture is crucial to the process. The fabricator must be able to measure the quality of the optic fast enough so that the parameters of the polishing process have not changed during the measurement process. The second profiler is now on loan from Photon Sciences to their subcontractor, Rockwell Power Systems of Albuquerque, NM.

3. Developmental Philosophy

Because of financial and time constraints LBL chose to work with a single vendor that was willing to implement the required metrology and share the developmental costs. A series of prototype electroless nickel on Glidcop blanks were ordered from the vendor without water cooling channels so the plating and polishing parameters could be worked out. After many plating experiments at several different vendors, we settled on Acteron Metal Finishers of Redwood City, CA. Their quality control and plated coatings are the best we have found. Not coincidentally, they are very committed to scientific metrology of their plating systems.

This policy of investing in state of the art metrology and placing it in the fabricator's shop has assisted other collateral areas of development in optical fabrication. Photon Sciences has constructed proprietary polishing machines for cylindrical surfaces that have made a 700 mm long cylinder with slope deviation from flat in the tangential direction of less than one arc second rms. The LTP has been essential in measuring this type of optic during fabrication and implementation of the polishing machine. In collaboration with Malcolm Howells[18] Photon Sciences is using integral bending technology developed in collaboration with LBL to make toroidal mirrors. The optic is bent convex by the integral bending fixture, and becomes a toroid upon relaxation after the generation of a cylindrical surface while it was in the stressed convex condition.

4. Results

As we mentioned above, 2 Angstroms rms is now routinely achieved on electroless nickel optics up to 15 inches in the tangential direction. This is a factor of five better than was routinely accomplished before our collaboration. It is no longer necessary to avoid metal components. The conventional brazing technologies can be applied to provide water cooling channels in a straightforward manner. This was not achieved without some trouble. Particular attention was necessary in the heat treatment of the nickel layer.[19] Silicon carbide, the other major developmental material for synchrotron related optics, because it is much harder than the nickel, takes several times as long to polish as the nickel. This greatly increases the cost of silicon carbide optics over the Glidcop and electroless nickel system.

We now select the ALS U5M1 mirror as an example of what can be achieved with the newly developed polishing and metrology systems, and first consider the errors in the LTP when used at the limit of its current performance.

5. Profiler Errors and Analysis

Figure 1 below shows schematically the operation of the Takacs style long trace profiler. Informally we call this model LTP II since it has the addition of the reference beams and the reference mirror designed to take out of the measurement any dependence of the measurement on the pitching error in the moving carriage. Even though laser beams interfere and produce fringes, the LTP is essentially an optical lever. Two sets of fringes are in place on the linear detector on the optical carriage, and the slope measurement is obtained by recording the difference in the centroid of the two fringe patterns. The addition of the reference beam has worked well in removing the effects of the pitching of the carriage down to a certain level. However, it has aggravated a problem common to many profiler instruments. In order to preserve the dynamic range of the device, the reference mirror is adjusted to place the fringe pattern from the two reference beams on one edge of the linear detector. The rays from the reference mirror go through the lens system at the edge of the aperture where the conversion from angle to linear position on the detector is slightly different than in the center of the field. This effect becomes crucial when measuring mirrors with slope error deviations from best fit sphere better than one half second of arc (2.5 micro radians rms).

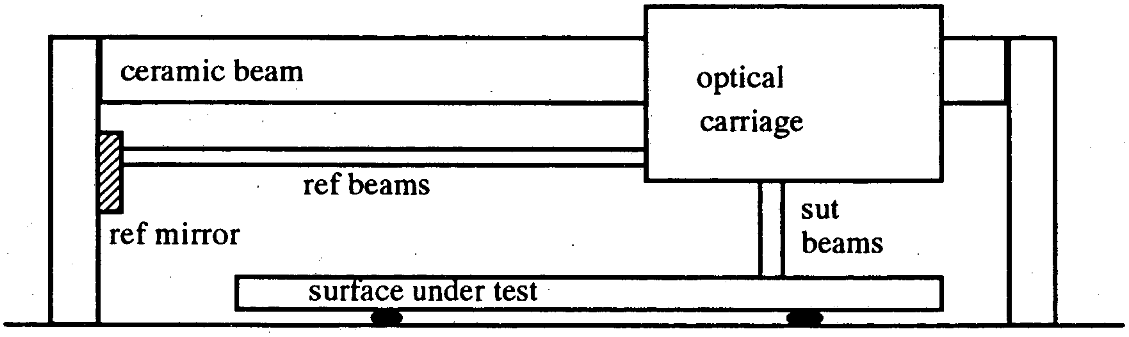


Fig. 1 Schematic diagram of a Long Trace Profiler, constructed by LBL (LTPII)

This effect is demonstrated by the data in figures 2 and 3. The first shows an LTP II measurement of the U5M1 mirror. A sliding average over 5 mm has been applied to smooth the data, and a best fit sphere has been removed from the slope data (linear term) The second figure shows a repeat measurement except that the mirror has been reversed 180 degrees before the measurement. If the majority of the two rms residual slope errors from these two measurements, (2.1 and 2.8 micro radians respectively), were indeed slope errors on the mirror, we would expect the patterns to reverse when we reversed the mirror. We suspect that the small peak structure is due to stray reflections of the laser beams in the profiler, and we believe that the majority of the overall shape of this curve is distortion in the angle to distance conversion of the optical system. These results require the optic under test to be mounted kinematically, with considerable attention given to the mechanical and thermal stability of the mounting on the profiler. The measurements were repeatable to 0.3 micro radians rms.

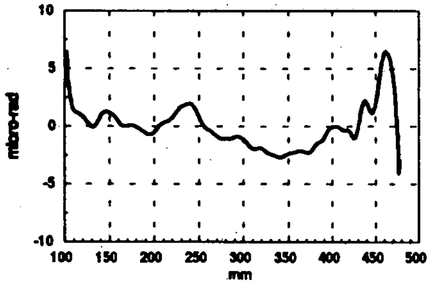


Figure 2. Original orientation of U5M1 during measurement, 2.1 micro-radians rms deviation from best fit sphere

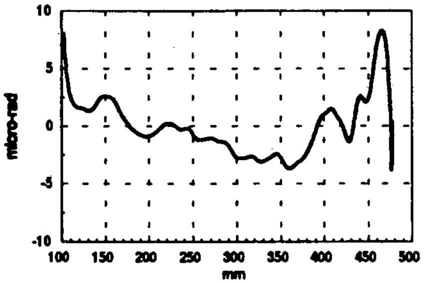
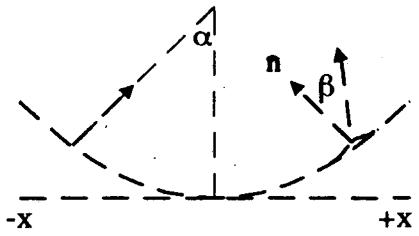


Figure 3. Reversed orientation of U5M1 during measurement, 2.8 micro-radians rms deviation from best fit sphere

These results do not indicate the limits of the current LTP II, however. Symmetry may be used to remove part of the error from these data. Since we are looking for sub arc second effects the slopes of the sphere that we are measuring are much greater than either the residual departures from spherical or the error in the lens system. These points are illustrated in figure 4 where alpha can be on the order of minutes, but beta--the sum of the departure from spherical plus the lens conversion error--is sub arc second.

Figure 4. This figure illustrates the symmetry of measuring a spherical part, and the assumptions about the relative magnitudes of the angles in the measurement.



In addition, there isn't any first order error in the residuals because it is calibrated away in the removal of the linear term from the raw slope data. These assumptions are incorporated in the following development. Setting the center of the mirror as x = 0, the first measurement may be written:

$$O[x] = S[x] + E[x] \tag{1}$$

where O is the original measurement of the slope, S is the true slope and E is the error of the system. The reversed measurement may be expressed similarly, where we have used the bilateral symmetry of the spherical surface to realize that the error is the same as long as the mirror is mounted in the same place and with the same tilt with respect to the profiler.

$$R[-x] = -S[-x] + E[x] \tag{2}$$

We next invert the data array measured as the left hand side of equation 2, giving:

$$R[x] = -S[x] + E[-x] \tag{3}$$

We now separately add and subtract equations (1) and (3) and divide by 2:

$$(O[x] + R[x]) / 2 = (E[x] + E[-x]) / 2 \tag{4}$$

$$(O[x] - R[x]) / 2 = S[x] + (E[x] - E[-x]) / 2 \tag{5}$$

When the equations are added to produce (4) only the even part of the error remains. This is demonstrated in figure 5 where the residual tangential slope data from the two measurements in the two different orientations have been added with one data set reversed. The fact that this approximates an even function shows that the mechanical and thermal properties of the profiler and its environment are adequate for our measurement. The rms value of 1.2 micro radians rms shows that a significant fraction of our original data came from systematic errors in the profiler.

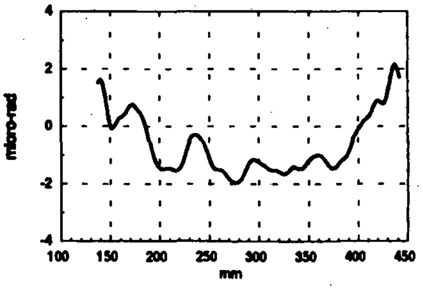


Figure 5. Results of added equations: even function part of error, 1.2 micro-radians rms deviation from best fit sphere

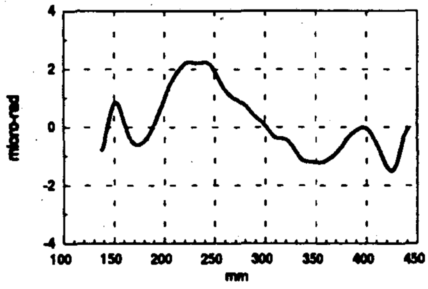


Figure 6. Results of subtracted equations: real slope plus odd function part of error, 1.1 micro-radians rms deviation from best fit sphere

When the equations are subtracted we have our final result in figure 6. This shows 1.1 micro radians rms deviation from best fit sphere in the tangential direction over 12 inches. This result is confirmed by independent and novel interferometric metrology at Rockwell Power Systems. See the following paper by Bender et al.[20] in this volume. Their measurement gave 1.1 micro radians rms over two different 7 inch long areas at the left side and right side of the free aperture of 12 inches that we present here. They measured 0.6 micro radians rms over the central 7 inches of the free aperture. Our data give 0.4 micro radians rms apertured over the central 7 inches, which compares favorably to their 0.6 micro radian rms measurement when we recall the 0.3 micro radians rms basic repeatability of our original unprocessed data.

6. Summary and Conclusion

We have reviewed the technical choices, key decisions, and results of the developmental program to produce water cooled optical components for the Advanced Light Source. Two Angstrom rms micro roughness and 0.2 arc second rms slope error deviation from best fit sphere are now routinely obtained on electroless nickel coated Glidcop mirrors and grating blanks up to 15 inches long. Identical optical metrology both at the customer and at the vendor is critical to establishing routine production of optical components for synchrotron applications.

The Takacs style long trace profiler (LTP II) at LBL has been shown to have an accuracy in rms tangential slope error of approximately 2 micro-radians rms in the raw data on a 15 inch long radius spherical part. The limit on this accuracy appears to be non linearity in the angle to distance conversion of the profiler optical system. Post processing allows the profiler to measure down to approximately 1 micro radian rms over the free aperture of 12 inches, and this result is confirmed by interferometric testing of overlapping smaller apertures. Over the central 7 inches of the part our measurement of 0.4 micro radian rms is an encouraging result, and indicates that one tenth arc second measurements may by possible with profiler systems. It must be reemphasized here that this measurement was obtained under excellent laboratory conditions, and that the mounting of the mirror in the profiler for both orientations was critical. We suggest that the optical metrology community involved in figure measurement of synchrotron mirrors organize and participate in comparative measurements of a series of test mirrors, so that differences in the performance of the various types of long trace profiler may be found and corrected.

7. Acknowledgements

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[1] Rense, W. A., and Violett. T. "Method of Increasing the Speed of a Grazing-Incidence Spectrograph," **Journal of the Optical Society of America,** 49 (1959) 139.

[2] W. R. McKinney, M.R., Howells, T. Lauritzen, J. Chin, R. DiGennaro, E, Fong, W. Gath, J. Guigli, H Hogrefe, J. Meneghetti, D. Plate, P. A. Heimann, L. Terminello, Z. Ji, D. Shirley, and F. Senf, **Nuclear Instruments and Methods in Physics Research,** A291, (1990) 221.

[3] H. A. Padmore, **Review of Scientific Instruments** 60, (1989) 1608.

[4] C. T. Chen and R. Sette, **Review of Scientific Instruments** 60, (1989) 1616.

[5] Takacs, Peter, Z., "Understanding The Performance of X-Ray Mirrors, in *Synchrotron Radiation in Structural Biology,* Sweet, Robert M., and Woodhead, Avril editors, Plenum Publishing Corp., 1989.

[6] Warwick, Tony, DiGennaro, Dick, and Howells, Malcolm, "U5 Beamline Design Document," LSBL-40 rev. 2, Lawrence Berkeley Laboratory, 1989.

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[7] Warwick, Tony, DiGennaro, Dick, and Howells, Malcolm, "U8 Beamline Design Document," LSBL-41, Lawrence Berkeley Laboratory, 1989.

[8] Heimann, Philip, "Changing the U8 M2 Mirror Demagnification from 15 to 8," LSBL-125, Lawrence Berkeley Laboratory, 1989.

[9] Glidcop is a trademark of Pittsburgh Plate Glass, and is obtained from SCM Metals in Cleveland OH.

[10] DiGennaro, R., Gee, B., Guigli, J., Hogrefe, H., and Howells, M.R., "A Water Cooled Mirror System for Synchrotron Radiation," Nuclear Instruments and Methods in Physics Research A266 (1988) 498.

[11] Swain, T.L., and DiGennaro, R.S., "Optical substrate design at the Advanced Light Source," **SPIE Proceedings** 1739 to be published.

[12] Micromap, Corp., Tucson AZ.

[13] von Bieren, K., "Pencil beam interferometer for aspherical optical surfaces," in Laser Diagnostics, Proc. SPIE 343, (1982) 101.

[14] Takacs, P. Z., and Qian, S., United States Patent 4884697, 1989.

[15] Takacs, P. Z., Feng, S. K., Church, E. L., Qian, S., and Liu, W., "Long trace profile measurements on cylindrical aspheres," Proc. SPIE 966, (1988) 354.

[16] Irick, S. C., "Determining Surface Profile from Sequential Interference Patterns from a Long Trace Profiler, "**Review of Scientific Instruments** Vol. 63 Pt IIB (1991)1432.

[17] Irick, S. C., McKinney, W. R., Lunt, D. L. J., and Takacs, P. Z., "Using a Straightness Reference in Obtaining More Accurate Surface Profiles from a Long Trace Profiler, "**Review of Scientific Instruments** Vol. 63 Pt IIB (1991)1436.

[18] Howells, M.R., and Lunt, David, "Design Considerations for Adjustable-curvature, :High-power, X-ray Mirrors Based on Elastic Bending," Proc. SPIE 1740 (1992) this volume.

[19] Schenzel, H. G., Kreye, H., "Improved Corrosion Resistance of Electroless Nickel-Phosphorous Coatings," Plating and Surface Finishing (1990) 50.

[20] Lunt, D.L., Bender, J.W., Ewing, D.G., and McKinney, W.R., "XUV synchrotron optical components for the Advanced Light Source--fabrication and metrology," Proc. SPIE 1740 (1992) this volume.

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