ISBN: 978-3-95450-188-5 doi:10.18429/JACoW-MEDSI2016-WEPE39

FABRICATION, ASSEMBLY, AND METROLOGY METHODS TO OPTIMIZE AN ADJUSTABLE EXIT SLIT FOR A SOFT X-RAY BEAMLINE

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Abstract

Exit slit edge geometry and paired edge parallelism can directly impact performance of a synchrotron beamline. At the same time, maximizing the performance of an existing design is often a financial and logistical necessity. The construction project for beamline 7.0.1 (BL7.0.1, Coherent Scattering and MICroscopy (COSMIC)) at the Advanced Light Source (ALS) facility located at Lawrence Berkeley National Laboratory (LBNL) consists of two branch lines, each of which has vertical and horizontal slit assemblies. These assemblies were fabricated from a pre-existing design, positively impacting project schedule and budget. Apart from orientation, the slit assemblies are identical. The goal for parallelism is +/- 2 microns over the full 25 mm length. Each Slit blade edge can travel +/- 5mm about the beam center with the resolution of a micron; slits can scan over that range with a nominal size of about 10 microns. A variety of fabrication and metrology techniques were implemented to maximize the performance of the current design and feature areas of improvement in fabrication, metrology, and design were identified.

INTRODUCTION

At the ALS, recently constructed beamlines 7.0.2 and 7.0.1 use eight sets of the exit slits described herein. Additionally, beamline 6.0 has five sets of similar design. In constructing new beamlines, existing designs are leveraged for the cost and schedule benefits they provide. Increasingly demanding specifications associated with new beamlines poses a challenge when leveraging these reused designs. After the construction of beamline 7.0.2, efforts were made to improve the performance of the exit slits on beamline 7.0.1 without resorting to a redesign of the assemblies themselves. These efforts resulted in varying degrees of success.

The COSMIC beamline, 7.0.1, has two branchlines and associated end stations. Each branchline uses two exit slit sets where one set confines the beam vertically and one set confines the beam horizontally. The goal was to have an exit slit parallelism of +/- 2 µm over the 25 mm length of the slit. Perpendicularity between the vertical and horizontal sets was not adjustable and resulted from the flange orientations on the welded chamber.

The blades themselves were made from OFHC copper, C10100 alloy, were paddle style blades, electrically isolated (and wired to measure current), and were water cooled for temperature stability. The blades were mounted to the end of actuators for insertion/retraction of the blades into/out of the beam to form a rectangular exit slit with adjustable dimensions and locations. Each blade signal was used in a feedback loop to steer the beam so that the position on the exit slit was consistent. The motion of the exit slit blades was not part of this feedback loop.

BLADE FABRICATION AND EDGE STRAIGHTNESS

The GD&T tolerance for the blade edge was a profile with a 1 µm tolerance zone. The initial fabrication used a fine wire EDM and were considered to be a "best effort". After cleaning, the edge was measured.

First Measurement

Metrology was performed on an Optical Gaging Products, SmartScope Quest 800 machine. Metrology software used was MeasureMind 3D v15.1

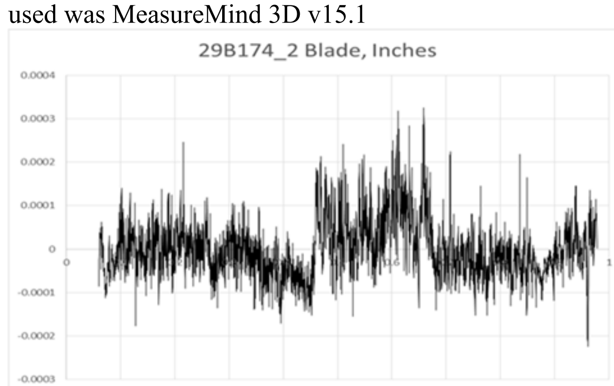

Figure 1: Typical first measurement.

Typical results (see Fig. 1) yielded a variation of the exit slit blade of +/- 2.5 µm to +/- 7.5 µm. As a result a lapping process was chosen for a secondary fabrication operation with the goal of improving the edge geometry of the blades.

Lapping Process

Simple blade fixturing maintained a consistent orientation relative to a surface plate. The blade edges were lapped using a series of graded abrasives (see Table 1). Lapping pressure and motion was done by hand by a journeyman machinist.

Table 1: Graded Abrasives

Abrasive	Grade
Roughing	1200 grit wet/dry silicon carbide
Semi-finish	3 µm (1500 grit), aluminum oxide
Finish	1 µm (2000 grit), aluminum oxide
Final Polishing	.1 µm (2500 grit), diamond

The lapping with grit paper was done by stroking repeatedly in sets of four, in one direction, at ~150 mm per second, along the direction of the blade length. Between sets, the lapped blade surface was visually inspected with a 10 X jeweler's loupe. A new area of abrasive was used after 3-4 sets of strokes. The blades were rinsed with ethanol and dried with compressed air at the time the new area of

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abrasive was introduced. Progressively finer grits were introduced when no change in the lapped surface was observed through the jeweler's loupe.

Cleaning Process

After lapping the blades were cleaned in the LBNL plating shop with the following sequence:

1. 909 Cleaner wash
2. Electro-polish at 130 F for < 1 minute*
3. Dip in nitric acid
4. Rinse in deionized water at 180 F

Second Measurement

The second metrology methodology was identical to the first.

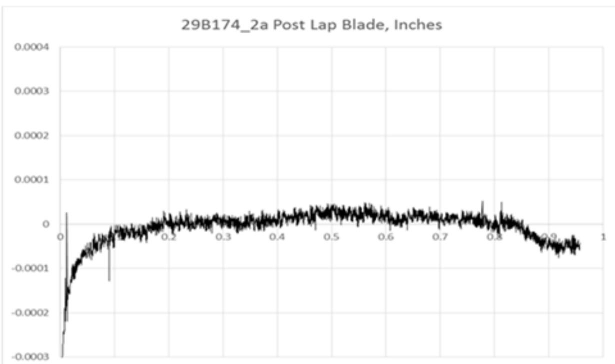

Figure 2: Typical second measurement.

The data (see Fig. 2) from 0 mm – 2.5 mm exhibited a consistent "fall-off" in the blades, indicating a greater degree of material removal from the lapping process. This was attributed to the manual lapping process as well as the asymmetric geometry of the lapped surface.

A single data point at 2.29 mm along the edge of -2.5 µm was observed in all the measurements. This point was interpreted as a digital artifact and not representative of an actual geometry and was removed in all subsequent data analysis. Other points were left in as their origin was unknown and they could have represented actual geometries of the blade edge.

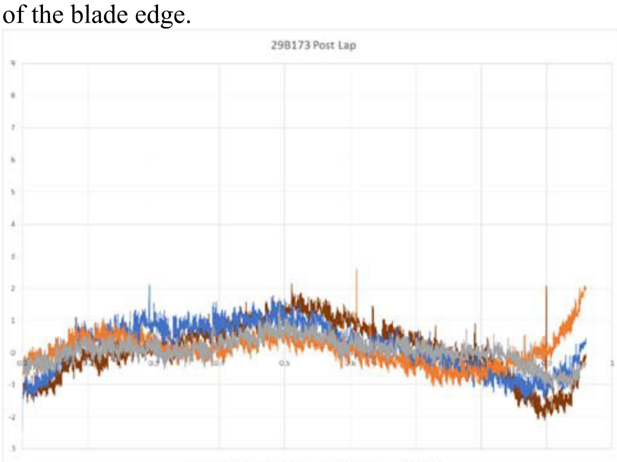

Figure 3: Second measurements for 29B173.

* The bath time ends when bubble formation is observed.

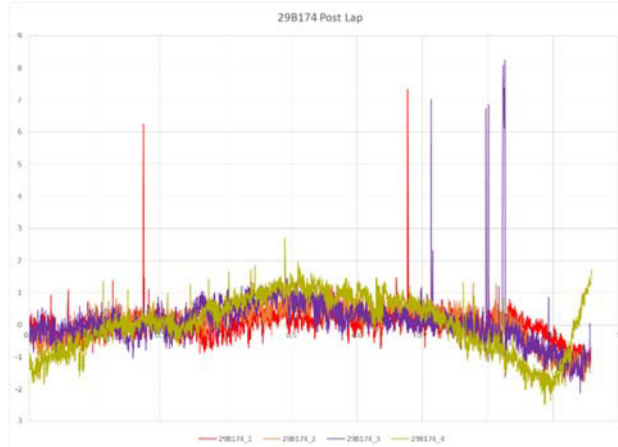

Figure 4: Second measurements for 29B174.

Excluding the "fall-off" region, the straightness measurement data for the eight blade edges had an RMS from .4 µm to 3.0 µm (see Figs. 3 and 4). It is unclear what of this was due to physical features and what was due to limits of the metrology methodology.

Edge Straightness Acceptance

The reworked edges of the blades did not fall within the specified 1 µm tolerance zone. The results of the rework were considered to be acceptable for the 7.0.1 beamline, particularly over the anticipated "short" 10 µm scan lengths.

SLIT PARALLELISM

The assembly of the slit sets were first done with conventional tools and measuring devices. The results were then measured with an optical measurement device (identical to the blade edge metrology). Iterations of adjustments were performed with feedback from metrology results.

Initial Assembly

Blade parallelism was adjusted using dial indicators. So as not to damage the blade edges themselves, indicator stylus contact was to the side opposite the blade chamfer (edge) side. This assumed parallelism between the edge and opposite side.

First Parallelism Measurements

The optical metrology device used was the same one used for the edge measurements. At 33.8 X power (optical) the parallelism of the blade edges was measured. The ends of ~2.5 mm were excluded to eliminate edge effects and limit the area of correction to the anticipated nominal working area. This left ~19.7 mm of slit length which is what is considered in all the following parallelism data. Best fit lines were created for each blade edge and these lines were adjusted for parallelism. Note, this method excluded any straightness issues with the blades.

First parallelism measurements of the conventionally assembled slit sets resulted in a range of 3 µm to 34 µm over the 19.7 mm slit lengths, compared to a specification of +/- 2 µm over 25 mm.

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Parallelism Adjustment

Each of the four sets were adjusted on the optical metrology machine, using measurement feedback for each adjustment iteration. Due to the stick-slip inherent in the mounting of the blades, the adjustment was to a best effort. The resultant parallelism was individually assessed. Adjustment iterations were generally less than five per slit set.

Parallelism Adjustment Results

Over the ~19.7 mm slit length, the parallelism results ranged from 10 µm to 0 µm. Slit set #3 was measured to be 3 µm after the initial assembly and was not adjusted. The results were considered acceptable over the 10 µm scan length and the assemblies were installed on the beamline as is.

FUTURE DESIGN CONSIDERATIONS

Possible improvements were documented during and after the fabrication, assembly, and installation efforts of the exit slit assemblies:

1. Add symmetric "lands" about the blade at the lapping surface to eliminate the lapping "fall-off".
2. Add lapping fixture specific mounting points, symmetric about the blade for even pressure application during lapping.
3. Add flexures for parallelism adjustment, possibly from outside the vacuum envelope.
4. Find or fabricate an edge standard of known straightness and finish to use as a point of comparison for the optical metrology, particularly over the smaller scale measurements.
5. Improve measuring edge straightness and parallelism over the 10 µm scan length.
6. Include metrology after installation and vacuum loading.
7. Replace linear ball screw translation stage with a flexure for consistent blade edge insertion and retraction.
8. Add physical anti-clash hard stops.

CONCLUSIONS

It was not possible to claim that the specification of +/- 2 µm parallelism over 25 mm was achieved. However, the results of the rework were a significant improvement over the original effort. Financial and schedule impacts of a redesign were avoided. Within the constraints of a beamline construction project, this fabrication was a success. The exit slit assemblies are expected to function for the beamline 7.0.1 and were installed. Performance will be gauged during/after commissioning in early 2017.

ACKNOWLEDGEMENTS

The Advanced Light Source and this work are supported by the Director, Office of Science, Office of Basic Energy Sciences, Division of Materials Sciences and the Division of Chemical Sciences, Geosciences, and Biosciences of the U.S. Department of Energy at Lawrence Berkeley National Laboratory under Contract No. DE-AC03-76SF00098.

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APPENDIX

The following Figures 5-11 show the before and after parallelism measurements for each of the four sets of slits. Units are in mm.

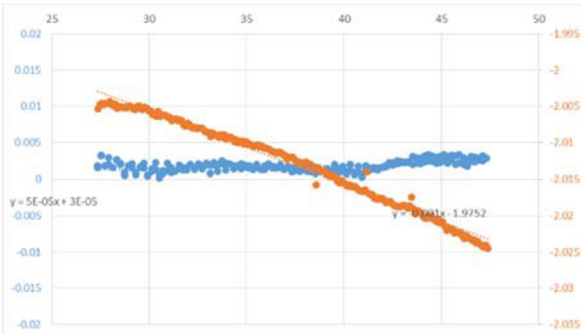

Figure 5: First measurements for Set #1.

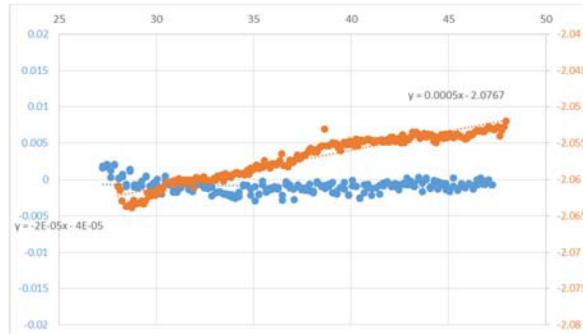

Figure 6: Second measurements for set #1.

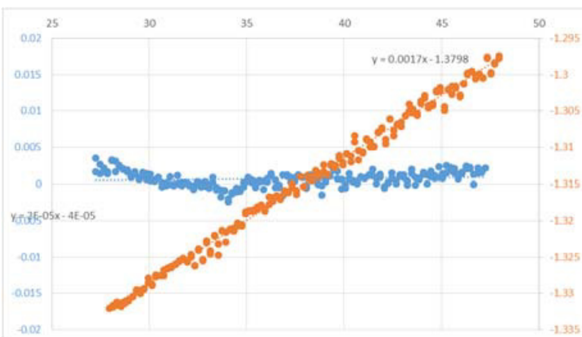

Figure 7: First measurements for Set #2.

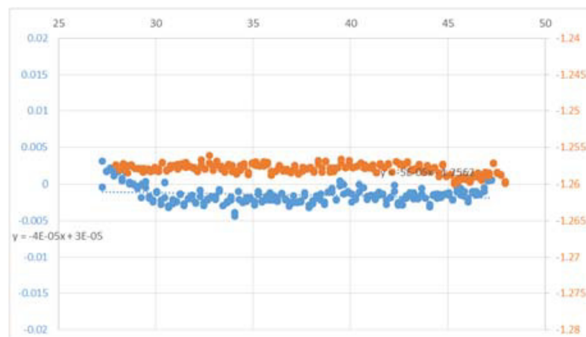

Figure 8: Second measurements for set #2.

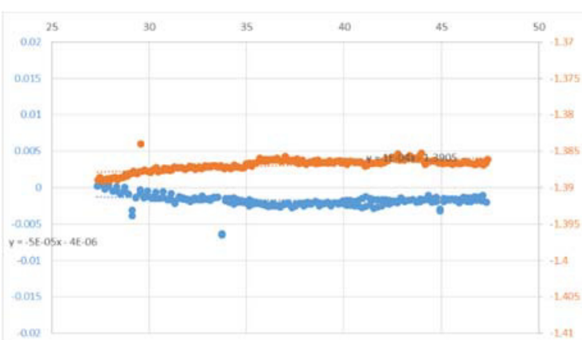

Figure 9: Only measurements for Set #3.

Set #3 was identified as having an acceptable parallelism and was not adjusted. See Table 2 for the tabular results.

Table 2: Parallelism Adjustment Results

(mm)	Preadjustment	Postadjustment
Slit# 1	0.021	**0.010**
Slit# 2	0.034	**0.000**
Slit# 3*	0.003	**0.003**
Slit# 4	0.026	**0.000**

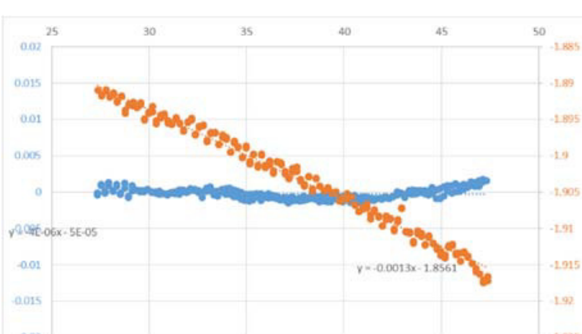

Figure 10: First measurements for Set #4.

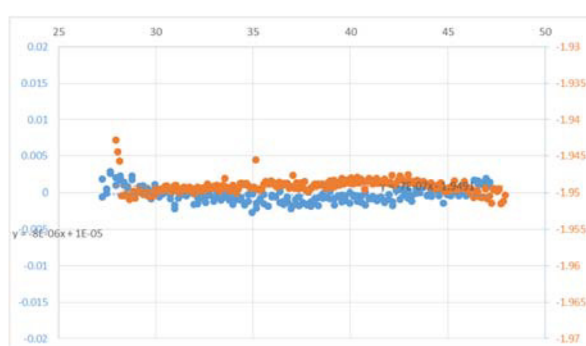

Figure 11: Second measurements for Set #4.