LCLS-S1 OPTICAL TRANSITION RADIATION MONITOR*

W.J. Berg, B.X. Yang, L.L Erwin, and S.E. Shoaf
Advanced Photon Source, ANL, Argonne, IL 60439, U.S.A.

Abstract

Argonne National Laboratory has developed a high-resolution optical transition radiation (OTR) imaging monitor for the Linac Coherent Light Source (LCLS) injection linac at SLAC. The imaging station, OTR-S1, will be located at the S1 spectrometer with a beam energy of 135 MeV. The system will be used to acquire 2-D transverse beam distributions of the accelerated photocathode-gun-generated electron beam. We anticipate an average beam current of 0.2 to 1 nC and nominal beam spot size of 130 μm (σx), 100 μm (σy). The imaging system was designed for a field of view x/y: 10 × 7.5 mm. The spatial resolution of ~12 microns was verified over the central 5 × 4 mm region in the visible. A 12-bit digital camera acquires the image and a Mac-based digital frame-capturing system was employed for the initial lab-based performance testing of the device. We report on system development, testing methods, and data analysis.

INTRODUCTION

Early on we had developed an OTR test station to prototype and test optical component configurations designed for an LCLS undulator system diagnostic [1, 2]. The development of an OTR device with similar field of view (FOV) and resolution requirements arose for use in commissioning the LCLS injector. This new system is located just upstream of the S1 spectrometer beam dump.

Given the fast track schedule considerations, we decided to take advantage of the existing undulator OTR test station development hardware. System modifications were performed to meet the physical conformance and physics specification of the new OTR-S1 monitor [3-5]. The newly configured station is depicted in Figure 1 [6]. We will discuss system hardware modifications and upgrades, optical configuration, testing methods, and results.

SYSTEM OVERVIEW

Two key requirements drove the system modifications presented here. In order to preserve control and image acquisition consistency throughout the injector, the LCLS standard 12-bit digital camera, UNIQ UP-900CL-12B [7], was specified. This called for the optical design to be adapted to a ½'' format CCD (demagnification of 0.65). Secondly, beam size parameters at the S1 spectrometer call for a large field of view while still maintaining high imaging resolution (see Table 1).

*Work supported by the U.S. Department of Energy, Office of Science, Office of Basic Energy Sciences, under Contract No. DE-AC02-06CH11357

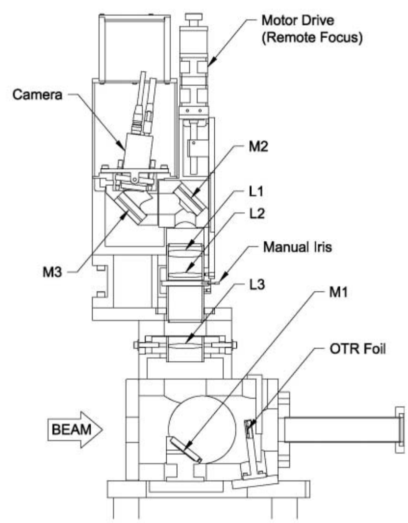


Figure 1: OTR-S1 assembly. The OTR foil is replaced with a pinhole array during laboratory bench testing.

Physical Restrictions

The optical path length is predominantly constrained by the original hardware configuration derived for use as an undulator system diagnostic. In addition, the remote controlled focus feature constricts lens placement within the apparatus such that at least one of the optical focusing elements must fall within the region of the motorized translation stage. The expedited time frame requirements for the project limited the lens selection to optics available off the shelf. To reduce chromatic optical distortion of the image, achromatic elements were incorporated.

Table 1: Beam and System Parameters [3-5]

Parameter	**Value**	
	x	***y***
Nominal beam size (σ_x, σ_y)	30 μm	100 μm
Minimum beam size (σ_x, σ_y)	21 μm	10-4000 μm
Field of view (*x, y*)	10 mm	7.5 mm
Resolution intended σ_{res}	12 μm	
Beam energy (γmc^2)	135 MeV	
OTR foil, aluminum (t, Ø)	1 μm, 10 mm	
½" CCD format pixels (H,V)	1392 × 1040	
Camera pixel size (H,V)	4.65 μm × 4.65 m	
Effective CCD size (H, V)	6.47 mm × 4.84 mm	

Optical Layout

Using Zemax optical modeling software, several optical configurations were simulated to yield the best geometry result considering the tradeoffs between resolution and field of view. Generally, a shorter working distance is desired when considering diffraction limits, but at the same time this can result in a decreased FOV. Demagnification of the original optical system to 0.65 in order to match the ½" format CCD produced a slightly shorter optical path length. The three-achromatic-focusing-element design chosen, as shown in figure 2, resulted in a calculated optical resolution of approximately 10 µm with 140 mm bandwith.

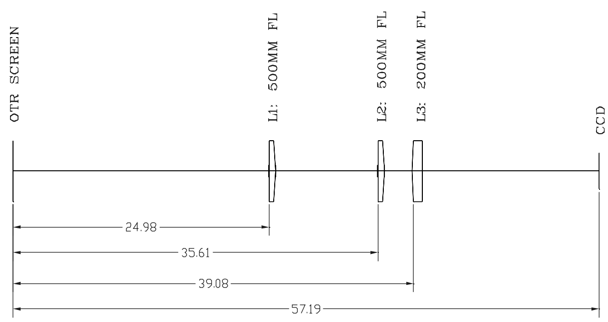


Figure 2: Nominal optical path configuration yielding a calculated optical resolution of approximately 10 µm with a 0.65 image demagnification.

System Modifications

The test apparatus was modified to accept the new optics configuration. Several mechanical design alterations were applied to simplify alignment adjustments and provide flexibility for adapting potential magnification changes. We selected a fixed OTR foil target design over an actuated version, as actuation is not necessary given that the device location precedes the S1 beam dump. The camera housing fixture was recessed to satisfy the shorter path length specified, and a camera-vertical-image-plane angle adjustment feature was incorporated.

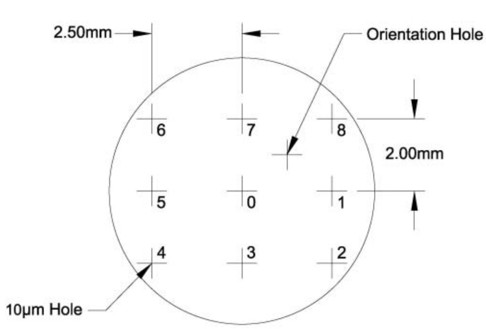


Figure 3: Pinhole Test Grid Layout (pinhole tol.: +/- 2 µm). *Note:* Reference orientation hole to account for optical image rotations induced.

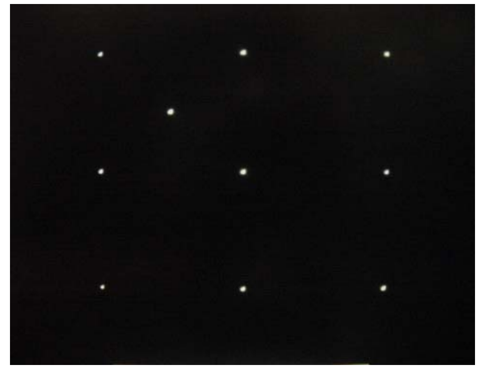


Figure 4: Photo of back-illuminated pinholes.

Test Configuration

For testing and alignment, the fixed OTR foil target was substituted with a 10 µm pinhole array (Figure 3). This calibration grid is cold back lit with a linear fiber bundle from a halogen light source as shown in Figure 4. The intensity was adjusted for the photo shown, but was greatly reduced to prevent saturation of the camera during testing. Mirror M2 was replaced with a 475- to 645-nm bandpass mirror to minimize chromatic aberrations induced from the halogen light source.

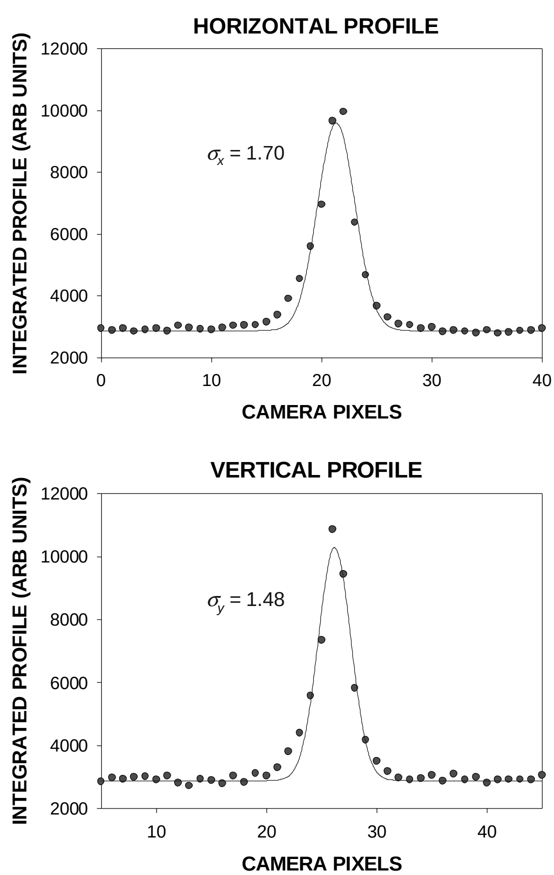


Figure 5: Integrated profile of the pinhole images in the horizontal direction (top profile) and vertical direction (bottom profile) fitted to Gaussian curves.

1-4244-0917-9/07/$25.00

The optics were final-aligned by hand using a live image on a video monitor. Focusing elements L2/L3 were translated on the motorized stage until the pinhole grid was visually in focus. The camera housing and L1 were positioned to center the image in x/y. A slight defocus, $\Delta z \sim 0.5$ mm, was used to make visual identification of the pinhole aspect easier to identify from the top to bottom of the grid. Finally, the camera vertical image plane angle was adjusted. This process was iterated until the image was well centered and had uniform focus across the grid.

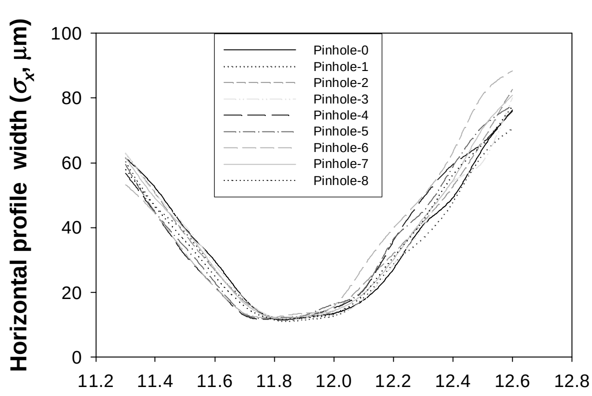
Calibration and Performance Measurements

The UNIQ digital camera was interfaced to an Active Silicon, Phoenix Camera Link 64-bit/66-MHz PCI frame grabber supported by a Power MAC G5 workstation. An in-house C program was used to convert the captured digital image data to ASCII format and then imported to Mathcad for processing. Figure 5 shows integrated profiles of the pinholes in the x and y directions fitted to Gaussian functions (σ_x=1.70 pixels, σ_y=1.48 pixels). Centroid pixel coordinates were determined and, using the Gaussian widths, we calculated the optical pixel size, field of view, and system resolution (based on the known distance between pinholes), see Table 2. The resolution derived from the individual pinhole Gaussian widths indicated that we had uniform resolution across the entire 5 mm × 4 mm grid.

Table 2: Measured System Parameters

Parameters	***x***	***y***
Optical pixel size (σ_x, σ_y)	7.41 µm	7.44 µm
System resolution σ_{res}	12.59 µm	11.03 µm
Field of view (*x, y*)	10.31 mm	7.74 mm

A focus scan was performed to verify that all of the pinholes were in focus (Figure 6). The curves indicate a minimum 12- µm rms profile width over a distance of $\Delta z \sim 250$ µm. The centers of the focus region differ by ~ 100 µm in the x and y directions. Beam based testing will be used to find the optimal resolution operating point given there is a slight offset in z introduced when the OTR foil replaces the pinhole calibration target.



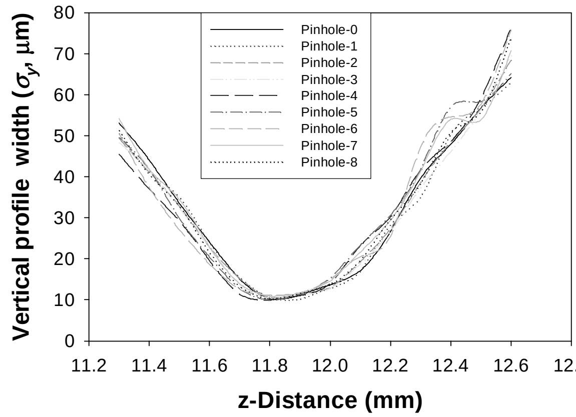


Figure 6: Gaussian widths of horizontal and vertical profiles of pinhole grid.

CONCLUSIONS

We have performed several necessary design changes to the LCLS Undulator OTR test station for use at the S1 spectrometer location. Bench tests show an rms optical resolution of ~ 12 µm over a 5 mm × 4 mm grid area. We believe that the resolution will be largely maintained over the entire field of view of 10 mm × 7.5 mm. The system has recently been installed into the LCLS injector. We look forward to commissioning of the OTR-S1 monitor and the operational results.

ACKNOWLEDGMENTS

The authors would like to thank Steve Milton and Carl Rego for their support of this project, and Paul Emma and Henrik Loos for informative discussions of the OTR-S1 requirements.

REFERENCES

[1] Bingxin Yang, “A design report for the optical transition radiation imager for the LCLS undulator,” LCLS Note, LCLS-TN-05-21, 2005.

[2] B.X. Yang, J. L. Bailey, D. R. Walters, and S. J. Stein, “Design of a high-resolution optical transition radiation imager for the linac coherent light source undulator,” PAC'05, May 2005, 4211, http://www.jacow.org.

[3] Physics Specifications for the Injector Profile Monitors (OTR and YAG), LCLS Physics Requirement Document, LCLS 1.2-021-r0, 2006.

[4] Physics Specifications for the Linac OTR Profile Monitors, LCLS Physics Requirement Document, LCLS 1.3-020-r0, 2006.

[5] Henrik Loos, Recent Work on OTR Diagnostics and Summary of PRD 1.2-021, (loos_1105_phys.ppt) and OTR Diagnostics in the Linac (loos_0306_phys.ppt).

[6] Engineering Specifications for the OTR Imager of S1 Spectrometer, LCLS internal communication.

[7] Uniqvision Incorporated, Santa Clara, CA, USA, uniqvision.com.