Optimizing x-ray mirror thermal performance using variable-length cooling for high-repetition-rate FELs.

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LCLS is part of the SLAC National Accelerator Laboratory located within the Stanford University campus in Menlo Park, CA.
Linac Coherent Light Source

- Uses last 1 km of 3-km linac
- e-beam energy: 2-14 GeV
- X-rays produced by ~100 m undulator
- Photon energy range: 250 eV-10 keV
- Pulse length: 1 - 100 fs
- 6 experimental stations
- >600 On Site Users per from over 30 countries
**LCLS - II**

South side source:
- 1.0 - 25 keV (120 Hz, copper linac)
- 1.0 - 5 keV (≥100 kHz, SC Linac)

North side source:
- 0.2-1.2 keV (≥100kHz)

4 GeV SC Linac
In sectors 0-10

14 GeV LCLS linac used for x-rays up to 25 keV
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From the current 2-300 mW to
up to 600 W on the optics

MEDSI 2016
LCLS-I Flat Mirror System Locations

FEE  NEH  XRT

FEE_M1  FEE_M2  XRT_M1  XRT_M2  XRT_M3

XCS  CXI  MEC  MFX

Ack: D. Cocco
LCLS Flat Mirror System Upgrade

- We need to upgrade the flat mirrors at LCLS to accommodate LCLS II upgrade
- Mirror Requirements:
  - Preserve wavefront in and out of focus
  - Optimized for lower power but with good performance at higher power (200 W)
  - Accommodate Variable beam footprint (from 70 to 400 mm FWHM)
  - Limit induced vibration
  - Avoid LN2, to limit contamination absorption

From the current 2-300 mW to up to 600 W on the optics
Motivation - Mirror shape errors requirements

- Preserve wavefront in and out of focus
- Optimized for lower power but with good performance at higher power (200 W)

From what we have now (1-2 nm rms shape error mirrors, limited acceptance)

Performance limited by surface quality (no heat load)
Motivation - Mirror shape errors requirements

- Preserve wavefront in and out of focus
- Optimized for lower power but with good performance at higher power (200 W)

From what we have now (1-2 nm rms shape error mirrors, limited acceptance) ..to what we need to have (< 0.5 nm rms, 2 FWHM acceptance) with up to 200 W on the mirror.

Performance limited by surface quality (no heat load)

Performance to be maintained with the heat load
Absorbed power profiles – Flat mirror case

Wide energy range leads to a highly variable beam footprint (from 70 to 400 mm FWHM)
Introduction to the Flat mirror system

It is composed by:

- A nice and flat mirror
- Holder and bender
- Cooling system

A robust and stable vacuum and mover system (identical system has been procured for the HOMS upgrade project of LCLS) Build to specs.
Flat Mirror - Holder

3 Vertical and 2 horizontal restraints
Positioned outside the Bessel points, to minimize the induced deformation in the central area

LCLS –I flexure design
(similar to the McCarville design)
Removable, to accommodate different restraints
We will use the higher compliance restraints to reduce deformation

Horizontal pusher
Using the notch around the mirror

System tested with Jtec mirrors. No appreciable deformation seen.
Careful installation procedure has to be followed
The mirrors exist!

- First three (3) 1-m long mirrors for HOMS upgrade received in May 2016 at SLAC
- They are the best mirrors ever manufactured in the world!
- < 0.2 nm rms in the central 300 mm and < 0.6 overall
- R > 900 Km

Measured shape errors at parallel lines at the vendor premise
Thermal deformation – spherical part

The deformation include a spherical thermal bump (dash lines) and residual shape errors.
Flat Mirror - Bender

We Need to preserve the flatness – R>900 Km
(with and without heat load)

• Successfully optimized installation procedure to do not introduce stress on the mirror (measured R > 1000 km!)
• Tested effect of each restrain (no visible mirror deformation)
• Tested the bender reproducibility (impressive preliminary results)
We Need to preserve the flatness – R>900 Km
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Metrology Laboratory

Class 1,000
Based on 16 HEPA filter
Enclosure provided by clear vinyl curtain

Humidity and temperature controlled by maintaining stable the circulating air.
Temperature stability: +/- 0.1°C with up to 8 people in the room (by design) at 85°F
Humidity: +/- 2.5% at 50%
Fizeau Interferometer

- We have 3 thick, very flat references for our interferometer.
- 1 $\lambda/300$, 1 Dynaflect $\lambda/300$ (4%LT), and one $\lambda/50$. 
Test results on the bender

Several rounds of measurements performed (>1000 measurements)
Designed to compensate radius of 250 Km (expected to be able to compensate radius as short as 150 Km)
Grazing Incidence Measurements

The bender induces a small, low special frequency residual cubic error term measured in grazing incidence (~10nm PV). Resolution is ~1/5th Normal Incidence at a Grazing Angle of 5.6 degrees (~0.5nm).
Thermal deformation – aspherical part

The deformation includes a spherical thermal bump (dash lines) and a residual shape error.

<table>
<thead>
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<th>Photon Energy (eV)</th>
<th>Power (W)</th>
<th>Radius (km)</th>
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<td>300</td>
<td>20</td>
<td>1,800</td>
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<td>800</td>
<td>20</td>
<td>920</td>
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<td>200</td>
<td>~470</td>
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<tr>
<td>1300</td>
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<td>~200</td>
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Mirror X (m)

300 eV; 20 W
800 eV; 20 W

Thermal deformation (nm)
Thermal deformation

The deformation include a spherical thermal bump (dash lines) and a residual shape errors.
Thermal deformation

The deformation includes a spherical thermal bump (dash lines) and a residual shape error. Thanks to the notch, the induced spherical thermal bump can be minimized for a range of beam footprints.

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Thanks to the notch, the induced spherical thermal bump can be minimized for a range of beam footprints.
Effect of Cooling Footprint on Performance

The ideal scenario is when the cooling length matches the beam FWHM.
A simplified solution uses five cooling circuits (3 cooling lengths) to mimic the beam footprint:

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<th>Energy Range (eV)</th>
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<td>&lt; 400</td>
<td>700</td>
</tr>
<tr>
<td>~ 400 – ~ 800</td>
<td>300</td>
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<tr>
<td>&gt; 700</td>
<td>100</td>
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The mirror is cooled from one side only. It has a trough located 5 mm from the surface hosting the GaIn eutectic. A notch, 20 mm from the surface, is used to reduce the thermal bump, and hold the mirror.
Flat Mirrors (HOMS/SOMS) design – in focus

The ideal scenario is when the cooling length matches the beam FWHM. A simplified solution uses five cooling circuits (3 cooling lengths) to mimic the beam footprint.

Red=perfect mirrors; Blue=with thermal deformation

In Focus
Flat Mirrors (HOMS/SOMS) design - out of focus

The ideal scenario is when the cooling length matches the beam FWHM. A simplified solution uses five cooling circuits (3 cooling lengths) to mimic the beam footprint.

@1300 eV
200 W

Profile at +20 mm from focal plane

Profile at +1 mm from focal plane

@ 500 eV
200 W
Close to Focus

@ 500 eV
200 W
Far from Focus
Future development: REAL (Resistive Element Adjustable Length) Cooled Optics

1) Add to the existing fins, used to cool the mirror, some resistive heaters

Project funded by BES over two years

Heat load from X-ray
Future development: REAL (Resistive Element Adjustable Length) Cooled Optics

1) Add to the existing fins, used to cool the mirror, some resistive heaters

2) Apply the proper power to the proper heaters to equalize deformation on the mirror

Project funded by BES over two years
Next steps

• Test prototype mirror with Gallium indium
  • Measure static vibration performance
  • Measure influence of cooling on vibration
    - Ensure proper chiller performance
• Test REAL cooling technique
• Install mirrors in LCLS I with no cooling in March 2017
• Full LCLS II upgrade with cooling beginning ~June 2018
Acknowledgements

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Under Daniele Cocco

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Axilon,
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Questions?