FEL Wave-front and Intensity Measurements at the BL beamlines at FLASH

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1. Beamline commissioning
   A first implementation as well as long-term observations of diagnostic tools and optics can be facilitated.
   • Mirror alignment of BL1 and BL2
   • Effects of filters and gas attenuator on FEL wavefront
   • Future of WFS measurements.

2. Problematic beam intensity diffraction patterns observed at the beamlines, first noticed by PMMA measurements.

3. Possible sources of the interference pattern problem.
Experimental hall

Flash conditions

VUV and soft x-ray regime
- 50 nm - 6.5 nm
- spectral shot to shot fluctuations
- higher harmonics up to the 7th
- particle-free UHV

High intensity levels
- ~10 - 50 µJ
- intensity fluctuations of two orders of magnitude

Pulse durations of 10 - 50 fs

Variable time structures
- 2 or 5Hz bunch train repetition
- 1-300 bunches in train
- 1-800 bunches with 10Hz in the near future
Wavefront sensor setup at FLASH beamline

Beamline BL 1

- gold mirror
- Wave front sensor 8 m behind focus
- BL 1 focus

- Hartmann plate
- flat gold mirror
- Pinhole chamber 2, 5, 10, 15 µm
- focal spot

Beamline optics:
- BL2 ellipsoid: 2m focal length
- BL1 toroid: 10 m focal length
  approx. 70 m behind FEL source
The Hartmann sensor principle

- Wave front sensor
- Soft- and hardware by Imagine Optic
- CCD: field of view = 19.5 x 19.5 mm
  1340 x 1300 pixels
- Hartmann plate: 51 x 51 quadratic holes
  tilted by 25° to prevent interference of adjacent holes

The actual beam is compared to a perfect spherical wave

 Courtesy Pascal Mercère, SOLEIL
Typical misaligned wavefront

Beamline BL2 before alignment

Rotation: 0  Yaw: 0
PV: 110 nm  rms: 22 nm@ 27 nm
→ \lambda/1
Radius (2\sigma) : 42.3\mu m

Ray tracing modeling for BL2:
FWHM: 20 \mu m → radius (2\sigma): 16\mu m

File: 08081016.himg
Before adjusting ellipsoidal mirror of BL2

Rotation: 0 Yaw: 0
PV: 110nm  rms: 22nm @ 27 nm → λ/1

File: 08081016.himg

defocus 100mm radius 164.9µm

defocus 50mm radius 87.8µm

defocus 0mm radius 42.3µm

defocus -50mm radius 88.9µm

defocus -100mm radius 166.0µm
During adjustment of BL2

- Defocus: 100mm, radius 170.7µm
- Defocus: 50mm, radius 88.1µm
- Defocus: 0mm, radius 27.7µm
- Defocus: -50mm, radius 88.3µm
- Defocus: -100mm, radius 170.9µm

Rotation: 45000 (~1 mrad)
Yaw: 0
PV: 30nm  rms: 5nm @ 27 nm
→ λ/5

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After adjustment of BL2:

- Defocus: 100mm, radius: 165µm
- Defocus: 50mm, radius: 84.1µm
- Defocus: 0mm, radius: 24.1µm
- Defocus: -50mm, radius: 85.2µm
- Defocus: -100mm, radius: 166µm

File: 08081060.himg

Rotation: 45000 Yaw: -0.01
PV: 18 nm rms: 3 nm @ 27 nm → λ/9
Alignment of BL 1

Horizontal: 0
Rotation: 0 Yaw: 0
PV: 56 nm, rms: 10 nm @ 27 nm
→ λ/3
radius: 86.1µm
file 08042501.himg

defocus -1 m

Horizontal: -1 mm
Rotation: 21000, Yaw: 0
PV: 39 nm, rms: 7 nm @ 27 nm
→ λ/4
radius: 69.6µm
file 08042520.has

defocus -1 m

Horizontal: -1 mm
Rotation: 27000, Yaw: - 0.3
PV: 19 nm, rms: 3 nm @ 27 nm
→ λ/9
radius: 68.9µm
design value: 80µm
file 08042601.hmg
Filter and gas attenuator performance

FEL higher harmonics
- up to the 7th harmonic measured
- maximum intensity of second harmonic 1% of fundamental
- filters are required to either make use of these wavelengths or to eliminate any ill effects.

solid filters in BL2
- 0.2 µm thick Nb foil
- 0.2 µm thick Si foil
- 0.1 µm thick Al foil
- small wave front modifications @ 27 nm
- shorter wavelength maybe worse

gas absorber
- N₂, Ne and Xe for various wavelengths
- at 27 nm an absorption of 94% by N₂ does not change the wave front significantly

no filter

Al foil
Wavefront sensor of Laser Laboratorium Göttingen

Very compact design for use behind user experiments

- Laser drilled Hartmann plate
  - 7µm Al-Folie
  - YAG @ 1064nm, ~100mJ
  - 320µm hole pitch
  - Approx. 50µm hole diameter

- Camera:

Image on camera

Calculated wavefront
The PMMA measurements detected the presence of interference patterns in the beam, which a closer examination of the intensity measurements taken by the WFS confirmed.
Interference more obvious with larger apertures

10 mm x 10 mm aperture

5 mm x 5 mm aperture

3 mm x 3 mm aperture

All taken at BL2, $\lambda=26$ nm
Interference changes with wavelength

$\lambda = 26 \text{ nm}$ gives about 2.1 mm distance between fringes

$\lambda = 13.5 \text{ nm}$ gives about 1.1 mm distance between fringes
• The micro-focusing experiment on BL3 also reported having seen interference patterns. Sven was in England last week, otherwise I would have asked him for some pictures of this claim.

• The BL1 beamline, where we did WFS measurements only four months earlier, may show them as well. The intensity profiles from it are too poor to make out any interference.

• We assumed that the interference did not come from the last mirror at BL2, but from further upstream.

• The possibility of the light itself carrying these interference was discounted because they were very stable and seemed to always be in the same positions, or at least equally separated from shot-to-shot.
By inserting edges of mirrors and screens into the beam, we were able to find that the interference fringes of similar size to the ones we saw at 26 nm occurred in the vicinity of the spectrometer mirror. Maybe the BPM is to blame?
• The Beam Position Monitors (which weren’t functioning anyway) were taken out. No obvious problem was noted with them, but they’re still being looked at.

• We will need to take another series of intensity profile pictures of the beam with a ICCD camera to see if the problem has gone away with the BPM’s.

• If the problem is still there, we will need to start taking out pieces of FLASH put in since the last upgrade one at a time until we find the problem. It’s equivalent to doing exploratory surgery. We know there’s a problem in the machine somewhere, but we’re not sure on its exact location

• Any ideas on how to make this process less painful are welcome.
The FLASH Team


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visible laser light

FLASH experimental hall

BL3
BL1
PG2
PG1
BL2
FIR -Beamline