Performance Tests of the Photon Monochromator for Self-Seeding at FLASH

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Introduction

Different seeding schemes have been elaborated at DESY (Saldin, Schneidmiller, Yurkov et al.)

Seeding schemes aim to obtain either

• full longitudinal coherence
• short pulses (→ few 10 femtoseconds at FLASH, or even attosecond regime for X-rays around 1Å)
• higher harmonics (VUV → X-rays)
A SASE FEL is a brilliant source of radiation with a high degree of transverse coherence but limited longitudinal coherence due to startup from noise.

“Spikes” in time and frequency domain are causing problems for some experiments → Self-Seeding is the cure
Idea: seed a SASE FEL with a fully longitudinally coherent, narrow bandwidth laser pulse

Approach: no sufficiently intense table top lasers available in the VUV and soft X-ray region

→ use monochromatized radiation from another SASE FEL as a seed

Self-Seeding Principle

Spectral power distribution

behind 1st undulator  behind 2nd undulator

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Photon Beamline:

- 1:1 imaging of complex conjugated wavefront onto entrance of 2\textsuperscript{nd} undulator
- monochromator resolution \( \leq 20000 \)
- overall efficiency 10%
- match pathlength of e-bypass

\[ \Delta \lambda/\lambda \approx 10^{-4} \]
Photon Monochromator Beamline:

- **M1**: Cylindrical
- **M2**: Spherical
- **M3**: Plane
- **M4**: Spherical
- **M5**: Cylindrical
- Entrance slit: Spherical
- Exit slit: Spherical

**Total length: 22m**

**6 optical elements**
Results from photon monochromator tests at ASTRID (ISA, Aarhus, DK)

- monochromator (from M1 up to exit slit + gas cell behind) set up at bending magnet at ASTRID storage ring
- all vacuum chambers and mechanical systems (including Monochromator !) were made at IFA&ISA, Univ. Aarhus
- all mechanics successfully tested in the lab
- monochromator performance (accuracy and in particular resolution) tested with beam on all three gratings with rare gas resonances (in particular He)
Setup

Beam from ASTRID

Gas Cell

branch with M4 & M5 not used during tests, just assembled!
Mirror mechanics

~ 100mm

beam
roll
pitch
yaw

x
y
z
Monochromator mechanics

Axes of rotation (port for Heidenhain angle encoders)

Premirror (M3)

Triple Grating (Al dummy!)
Beam in

Ti Sublimation Pump

Beam out

Ion–Getter Pump

Pitch M3

Pitch Grating
View onto triple grating in monochromator
View onto triple grating in monochromator
Beam on entrance slit

10mm
Beam on grating
Results: resonance spectra

1) He $^1P^0$ double-excitation states around 60eV
Helium $^1P^0$: zoom onto $n=7^+$ to continuum high energy grating (HEG)

$\Rightarrow$ ~20,000 monochromator resolution, in agreement with specifications!

Changing from MEG to HEG, energies were only 13 meV (0.2‰) off!!
Coming from calibrated MEG, energies were only 40 meV (0.45‰) off!!
Ar 3p → ns, nd, HEG

Coming from calibrated MEG, energies were only 123 meV (0.5‰) off!!
## Resolving Power

<table>
<thead>
<tr>
<th>Energy [eV]</th>
<th>Gas</th>
<th>LEG</th>
<th>MEG</th>
<th>HEG</th>
</tr>
</thead>
<tbody>
<tr>
<td>~24</td>
<td>He</td>
<td>~ 8000</td>
<td>11000 -</td>
<td>16000 -</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[8000]</td>
<td>16000</td>
<td>22000</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(3 meV)</td>
<td>[15000]</td>
<td>[22000]</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>(4-6 meV)</td>
<td>(3-4 meV)</td>
</tr>
<tr>
<td>60-65</td>
<td>He</td>
<td>~ 5000</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>[5000]</td>
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<tr>
<td></td>
<td></td>
<td>(13 meV)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>91-95</td>
<td>Kr</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>244-250</td>
<td>Ar</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- blue: 40 micron slits, red: 20 micron slits, []: ray tracing values

- ≥ 4000 (≤ 25/60 meV) conservative estimate, limited by natural linewidth and data quality
Summary

• Self-Seeding will deliver FEL beam with almost full coherence, both transverse \textit{and} longitudinal

• Narrow bandwidth $\rightarrow \approx 50x$ higher peak brilliance with pulse energies comparable to usual SASE FEL

• Wavelength range at FLASH from about 60 - 6.4 nm

• Jitter free synchronization between seed pulse and electron bunch

• Monochromator performs according to specs!
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Ruben Reininger

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Supplementary Transparencies
**Requirements**

**Electron Bypass:**

- some dispersion needed to remove the microbunching, but avoid too large increase of total bunch length
- minimize deterioration of beam quality caused by coherent synchrotron radiation (CSR) in the dipoles (tolerable limit of about 10 % growth of the slice emittance)
- small central "tuning bypass" to vary the electron beam pathlength by about 1 mm is necessary to cope with the changes in photon beam pathlength introduced by changing the monochromator energy
Final Layout

Electron Bypass:

11 steerers, 8 dipoles, 8 quadrupoles (vert. foc.), 6 quadrupoles (hor. foc.), 4 sextupoles

37 magnets total

Photon Monochromator Beamline:

Total length: 22m
FLASH with Seeding Option

ELECTRON-GUN → ACC1 → BC2 → ACC2 → ACC3 → BC3 → ACC4 → ACC5

LARGE ELECTRON BYPASS

1st UND. Photon Beamline

SEEDING OPTION

2nd UNDULATOR → ELECTRON DUMP
Mirror M2 in holder
Rolf Treusch, DESY-FS

Accuracy of grating/premirror drive

Locally (within few eV) energy scale error up to ~ 1% (some 10 meV), but globally better than 0.5‰, even upon grating change!

Can/will be improved but is not crucial since we will use feedback from Heidenhain rotary encoders (RON 905 UHV, accuracy +/- 0.2", can be even interpolated to better accuracy)

±3" per 0.2degree or ±4.5 μm per 1mm (= one turn) due to spindle reeling/wobbling
Helium $^1P^0$: zoom onto n=7+ to continuum, medium energy grating (MEG)
Helium I around 24 eV, low energy grating (LEG)
Plotting the "Resolving Power" against Photon Energy (eV) for different exit slit sizes: 20 μm, 40 μm, and 100 μm.

- **Rectangles** indicate measurements.
- **Rectangles with a dot** represent ray-tracing results (R. Reininger).

Legend:
- ■: measurements
- □: ray-tracing results (R. Reininger)