Beam Dynamics Optimization for the Hard X-ray Self-seeding at European XFEL

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Outlines

- Work transfer from Guangyao Feng
- Hard X-ray Self-Seeding (HXRSS) simulations
- Beam dynamics optimization for HXRSS
- Preliminary results of optimization
- Future plans for S2E simulation
1. EXFEL
   - **S2E simulations** (20pC, 100pC, 250pC, 500pC, 1nC SASE1 & SASE3)
   - Bandwidth calculation for SASE1
   - Radiation calculation for SASE1 with optimized tapered undulator
   - Short X-ray pulses with emittance-spoiler foil method
   - **Energy dechirper study with flat top current profile** (250pC, 500pC)

2. FLASH
   a. S2E simulation for FLASH1
   b. FLASH2
      - S2E simulation for SASE, Ip=2.5 kA
      - Beam dynamics study for low slice energy spread
      - Examples of S2E simulation for seeded FEL study for FLASH2 (Ip ~ 1.0 kA)

3. Other Matlab scripts
S2E simulation to get flat top current profile with 100pC for the HXRSS at EXFEL

Code used in simulation

Injector - ASTRA
ACC1 - ASTRA
ACC39 - ASTRA
Laser Heater - CSRTrack
Straight section - ASTRA

Electron Source
Dogleg - CSRTrack
BC0 - CSRTrack
Linac1 - ASTRA
BC1 - CSRTrack
Linac2 - ASTRA
BC2 - CSRTrack
Linac3 - ASTRA
Collimator - CSRTrack
TL+T2 - ASTRA

X-ray Source
Stage 1 - Genesis
Stage2 HXRSS - OCELOT
Stage 3 - Genesis
Stage4 HXRSS - OCELOT
Stage 5 - Genesis

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Flat-top current distribution (increase of $\sigma_z$)
-> mitigate the CSR effect in collimation section
-> mitigate the distortion in longitudinal phase space in the center
Combination of high rep-rate HXRSS and Tapering

- Tapering: increases power
- HXRSS: decreases bandwidth

- Used S2E simulation beam distribution (from 2013) before undulator as input
- Short bunches (FWHM<20µm) are preferred (longer bunches -> larger spatio-temporal coupling effect)
**HXRSS simulation status**

- Lower photon energy (<12keV)
  - Less than 6 undulator cases
    - works well
- Higher photon energy (e.g. 14.4keV)
  - More than 6 undulators cases
    - multi-peaks in power distribution
    - SASE noise in spectrum

Flat energy distribution in the center preferred for HXRSS performance study:

- What is the critical energy for HXRSS?
- How many undulators should be reserved for 1st and 3rd stage?
Optimization procedures

- Global compression function
- Inverse global compression function

• 2\textsuperscript{nd} deviation $Z_3'$ -> symmetry of current distribution
• 3\textsuperscript{rd} deviation $Z_3''$ -> flatness of current distribution (FWHM)
• 1\textsuperscript{st} deviation chirp -> change compression (keep 5kA of peak current)

17.5GeV, 100pC, 5kA case. Optimization performed with RF tweak 5*

*Igor Zagorodnov and Martin Dohlus

*Bolko Beutner, FEL Seminar 17.2.2015
Comparison of distributions after BC1

Before Optimization

After Optimization

Comparison of distributions after BC1
Comparison of distributions after BC2

Before Optimization:

FWHM ≈ 12 fs

CSR impact

After Optimization:

FWHM ≈ 15.5 fs

CSR impact
Comparison of distributions before collimator

Before Optimization

After Optimization

Space Charge impact (in L3)
Comparison of distributions after collimator

Before Optimization

After Optimization

CSR impact (in collimation section)

CSR impact (in collimation section)
Comparison of distributions before undulator

**Before Optimization**

- FWHM ≈ 12 fs

**After Optimization**

- FWHM ≈ 15.5 fs

*4% bad particles removed from head and tail*
7+7+10 undulators
14.4 keV case

Radiation power
E & ΔE
Radiation phase
Spectrum intensity

"single spike"

"flat top"

HXRSS simulation results comparison
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HXRSS simulation results comparison

Radiation power

Total spectral intensity

after 7+7+12 undulators, tapering not implemented yet …
Averaged total spectral intensity (15 events)

Increased by factor ~2

$\Delta \lambda / \lambda \sim 4.3 \times 10^{-5}$

$\Delta \lambda / \lambda \sim 7 \times 10^{-5}$

$\Delta \lambda / \lambda \sim 2.3 \times 10^{-3}$
Future plans

- Further HXRSS studies with 100pC case
- Improve (atomization) of optimization procedure?
- Energy chirp optimization for other charges (20pC, 1nC)
- Add wakefield in collimation section
- S2E simulation for SASE2
- Simulation with updated gun parameters
- Compare simulation results with commissioning results
- …
Thank You!

- Thanks to Guangyao Feng for all the information and discussions!
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