## Optimizing performance of Apple-X

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EuXFEL operator training, Hamburg, 18.11.2024





HELMHOLTZ

#### **Typical user experiment**

- X-ray magnetic circular dichroism (XMCD) in some metals (usually Fe, Co, Ni, ...), possibly pump-probe using optical laser;
- Difference in absorbtion for left/right circular polarization is measured;
- The most important property is polarization purity which is defined by the contrast (pulse energy ratio when Apple-X is on/off resonance);
- Typical numbers: 1 mJ on-resonance, 20 uJ off-resonance (i.e. linearly polarized light coming from SASE3), the contrast is 50.
- High pulse energy might not be required for these experiments but could be important for other experiments.



## **Optimization goals**

- Contrast as high as possible, i.e. pulse energy from SASE3 must be minimized;
- Pulse energy from Apple-X as high as possible;
- Good transverse shape and pointing of the photon beam.

We do not consider short pulses here.

#### The method: reverse tapering of SASE3



- Fully microbunched electron beam but strongly suppressed radiation power at the exit of reverse-tapered planar undulator
- The beam radiates at full power in the helical afterburner tuned to the resonance

E. Schneidmiller and M. Yurkov, Phys. Rev. ST-AB 110702(2013)16

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#### **SASE3 simulations (2013)**





Evgeny Schneidmiller and Suren Karabekyan

## **FEL commissioning of APPLE-X**

- Number of segments and reverse taper strength are close to simulations from 2013;
- Photon energy was usually 1 keV, pulse energy 1 – 1.5 mJ and the contrast up to 90;
- Different polarization states tested.





#### **Tuning iterations**

- Coarse tuning of SASE3; Apple-X in "no light" state or far from resonance. The main goal is to establish proper suppression of Sa3 intensity while hoping for bunching preservation;
- **Coarse tuning of Apple-X**: optimize orbit and K-value;
- Fine tuning of SASE3: optimize reverse taper strength and number of segments plus additional tricks;
- Fine tuning of Apple-X: further improve orbit, check phase shifters (usually ok), try linear or quadratic taper (positive) ...

#### Possible shortcut

Restore settings for SASE3 and Apple-X from a recent good regime using E-photon energy change tool (incl. quad movers); then do fine tuning.

## **Coarse tuning of SASE3**

- Start with normal SASE, untapered undulator; use 10 last segments; Apple-X off-resonance;
- When not in interleaved mode: L2 or L3 chirp should be on the left from the maximum (compress weaker with ~ 10% reduction of intensity);
- Vary number of segments to be roughly at saturation; aim at ~ 2 mJ (typically 9 – 12 segments);
- Make sure that the beam is not far from the center on FEL imager;
- Apply reverse linear taper (typically between -150 and -200): pulse energy should be ~ a couple of tens uJ (use fast XGM signal even if it is not accurate at this level).







#### **Coarse tuning of Apple-X**

- Close all 4 segments, go to C+ (or C-) mode and optimize photon energy (the optimal value is usually lower than Sa3 by roughly 10 eV); few eV offset can spoil beam shape;
- Close Apple-X segments one by one, optimize steerers in front; also quad movers in front of the 1<sup>st</sup> and the 3<sup>rd</sup> segments;
- Try not only to improve pulse energy but also watch FEL imager, avoid bad shapes.

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#### **Fine tuning of SASE3**

- Try to optimize both the contrast and the pulse energy from Apple-X; for this move Apple-X on/off resonance after some changes in SASE3;
- Vary two main parameters: number of segments and linear taper strength;
- As a refinement, play with phase shifter in front of the last segment #23, and with K-offset of this segment;

• ...

#### **Fine tuning of Apple-X**

- Check phase shifters in Apple-X (usually ok at nominal settings though);
- Try linear or quadratic taper (positive);
- Do fine adjustment of orbit and photon energy;
- ...

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#### **Contrast measurements**

- When Apple-X is off resonance, pulse energy from Sa3 is at 10-20 uJ level; fast signal of the XGM is very inaccurate;
- Increase number of bunches to several tens, use slow (ion signal);
- For calculation of pulse energy it uses sum of number of bunches in Sa1 and Sa3; for the contrast calculation this does not matter but for absolute energies one can correct by the factor (N\_sa1+N\_sa3)/N\_sa3.

Name	Auto	Manual	Used values
Gas Type:	3		COO Krypton
Cross-Section:	0.41358 Mb	R 0.00000 Mb	0.41358 Mb
Gamma:	3.11 Mb	0.00 Mb	3.11 Mb
Conversion:			1.006630E8
Current left:	3.25n	Offset: 410.0f D	3.25n A
Current right:	3.13n	Offset: -50.0f D	3.13n A
Current sum:			6.38n A
Current aux sum:			6.45n A
Detector length:	main: 21.93 cm	aux: 22.15	21.93 cm
Temperature:	23.58	1	23.58
SRG Pressure:	1.44E-5 mbar		000 1.44E-5 mbar
RVC Pressure:	2.10E-5 mbar		2.10E-5 mbar
Nr. of Bunches:	52.00	2.00 E	52.00 52.00
Wavelength:	1.2398 nm	2.7600	1.2398 nm
Undulator open:	0		0
Undulator moving:	0		0
Rep. rate:	10.00		10.00
Delay:	100.01	200.00	100.01
HV supply:			4072.60 3974.5 5974.51 - 175.323 - 2.0534
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1280- 1260- 1240- 1220- 1200- 1180- 1160-	0.710-AFD10 (MJ 0.7100NTENSITY.SLOW.TRAIN (MJ	]	



#### **Useful remarks**

- Photon energy change within a small range (few tens eV) can be simply done by parallel shift of Sa3 and Apple-X;
- Changes ~ 100 eV may require additional tuning (mainly number of Sa3 segments and taper strength), steering to the reference orbit;
- Switching between C+ and C- is quick, same performance;
- Pulse energies for linear polarization are smaller by roughly a factor of two than for circular - no worries, expected from theory;



From C+ to C- and back

# **Backup slides**

#### **Reverse taper in a nutshell**

- Reverse taper = increase of K-value along the undulator length (in contrast with reducing it in case of post-saturation taper).
- In case of SASE, reverse taper creates frequency detuning: radiation frequency at a given position in the undulator is blue-shifted w.r.t. resonance frequency for a current K-value.
- This shift is responsible for the effect: bunching is strong at a weak e.m. field.
- In a seeded FEL the blue shift can be created w/o reverse taper, just by K-offset.
- The effect can be easier understood in the steady-state regime: detuning from resonance creates strong disbalance between the three quantities: e.m. field, energy modulation and bunching (backup slides).