

Undulators production and commissioning for the European **XFEL**

Suren Karabekyan

Argonne National Laboratory

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Part II Motion Synchronization – On-the-fly energy scan mode

Possible synchronization scenarios



Possible synchronization scenario

Proof of principal



Tolerable Following Error Change gap with "Laser ON" condition

$$B_0(g/\lambda_0)[T] = a \exp\left\{b\frac{g}{\lambda_0} + c\left(\frac{g}{\lambda_0}\right)^2\right\}$$

	SASE1/2 U40	SASE3 U68
а	3.10487	3.2143
b	-4.24914	-4.62305
C	0.80266	0.92541

 $\frac{\partial B}{\partial g} = B\left(\frac{g}{\lambda}\right) \left\{\frac{b}{\lambda} + 2c\frac{g}{\lambda^2}\right\}$

 ρ is FEL (Pierce) parameter



SASE1/2 Gap [mm]	∆g [µm]	SASE3 Gap [mm]	∆g [µm]
10	-3.1	10	-16
20	-3.5	25	-17



Following Error Possible scenarios:

- Δg < 3.1µm
 Fullfils ρ<3 x 10-3 for SASE1-3;
 Full lasing 'On the Fly'
- Δg > 3.1µm to Δg <≈ 6µm; ρ<≈6 x 10-3 SASE1/2 Lasing with reduced performance; SASE3 OK
- Δg > 6µm to Δg <≈ 16µm; ρ≤ 1x 10-3 SASE1/2: Limited to no use SASE3: Full lasing 'On the Fly'
- ▲g > 16µm to ∆g <≈ 25µm SASE1/2: no way SASE3: Lasing with reduced performance



Speed limitation Monochromator Drivern Modes

Speed is set by the energy scan speed of the monochromator: \approx 1eV/sec

$$E1[eV] = 2.48311 \cdot 10^{-4} \frac{\gamma^2}{\lambda \ [mm](1+0.5K^2)}$$
$$\frac{dE1}{dgap} = 2.48311 \cdot 10^{-4} \frac{-\gamma^2 K^2}{\lambda_0 [mm](1+0.5K^2)^2} \left\{ \frac{b}{\lambda} + \frac{2c \cdot gap}{\lambda^2} \right\}$$

Limitation by Monochromator: \approx 1eV/sec

	Gap [mm]	E1 [eV]	$\frac{dE1}{dGap}$ [ev/mm]	Speed [µ/sec]
SASE1/2	10	7912	1300	< 1
	20	36407	3000	<<1
SASE3	10	780	97	10
	25	5287	537	2

<u>Conservative</u> speed requirements v < 1 to ≈100µm/sec



Real taper operation mode for XFEL

Includes
 Linear and
 Quadratic tapering

 Higher order terms are also possible

UndulatorTaperMain.xml XFELFEL/WAVELENGTHCONTROLSA2/XFELSA2/						
Undulator Taper Control Panel	SASE	SASE1 Undulator Server Pa				
WAVELENGTHCONTROL.SA2						
K Value Plots - StatterView K Value Plots - NuboView	Segment Taper Gr.	Actua	Predict			
	U40.2200.SA2 1 💌	3.3608000	3.3607850	Acti		
3.365 WAVELENGTHCONTROL SA2/U%K	U40.2206.SA2 1 💌	3.3606000	3.3605833	Acti		
3.36-	U40.2212.SA2 1 -	3.3604000	3.3603816	Acti 🖌		
3.355	U40.2218.SA2 1 💌	3.3601999	3.3600800	Acti 🗹		
3.35	U40.2224.SA2 1 🔽	3.3599999	3.3599784	Acti 🗹		
3.345	U40.2230.SA2 1 💌	3.3599999	3.3597767	Acti 🗹		
3.34- 0 X	U40.2237.SA2 1 💌	3.3598001	3.3595750	Acti 🗹		
3.337 9.20	U40.2243.SA2 1 💌	3.3594999	3.3594735	Acti 🗹		
3.33 3.325	U40.2255.SA2 1 💌	3.3591001	3.3591719	Acti 🗹		
3.32-	U40.2261.SA2 1 💌	3.3590000	3.3588700	Acti 🗹		
3.315- ° X	U40.2267.SA2 1 💌	3.3589001	3.3586185	Acti 🗹		
3.31	U40.2273.SA2 1 💌	3.3585999	3.3585668	Acti 🗹		
3.305-	U40.2279.SA2 1 💌	3.3585999	3.3583651	Acti 🗹		
3.3- O X	U40.2285.SA2 1 💌	3.3584001	3.3581636	Acti 🗹		
3.295 ×	U40.2291.SA2 1 💌	3.3582001	3.3579619	Acti 🗹		
3.29	U40.2297.SA2 1 💌	3.3580999	3.3577602	Acti 🗹		
3.285-	U40.2310.SA2 1 💌	3.3577001	3.3575585	Acti 🗹		
3.28	U40.2316.SA2 1 💌	3.3577001	3.3573570	Acti 🗹		
3.275	U40.2322.SA2 1 💌	3.3570001	3.3569536	Acti 🗹		
3.27 ⁻¹	U40.2328.SA2 1 💌	3.3559000	3.3561471	Acti 🗹		
[m]	U40.2334.SA2 1 💌	3.3545001	3.3549371	Acti 🗹		
	U40.2340.SA2 1 💌	3.3522999	3.3533239	Acti 🗹		
Wavelength Controls	U40.2346.SA2 1 💌	3.3497000	3.3513076	Acti 🗹		
wavelength Controls	U40.2352.SA2 1 💌	3.3464000	3.3488877	Acti 🗹		
Wavelen ĴĴŶĴ nm H Set	U40.2358.SA2 1 💌	3.3425000	3.3455646	Acti 🗹		
.7,000.00 eV H	U40.2365.SA2 1 💌	3.3383999	3.3426383	Acti 🗹		
	U40.2371.SA2 1 💌	3.3336999	3.3392086	Acti 🗹		
Sta Daady Exercy 14000 MeV	U40.2377.SA2 1 💌	3.3285999	3.3351758	Acti 🗹		
	U40.2383.SA2 1 💌	3.3227999	3.3307395	Acti 🗹		
Taper Group Controls Group actions	U40.2389.SA2 1	3.3164001	3.3259001	Acti 🗹		
Group 1/100 - e-5/cell, quadr 6.00 - e-5/cell, starting at 17 - All stop	U40.2395.SA2 1	3.3092999	3.3206573	Acti 🗹		
Group 2 ^{Linvar} _lineare-5/cell, quadr 0.00 + e-5/cell, starting at 0 + All to max. gap	U40.2401.SA2 1	3.3020000	3.3150110	Acti 🗹		
Group 3 ^{ΔAX/A:} 0.00 + e-5/cell, quadr 0.00 + e-5/cell, starting at 0 + Active to max gan	U40.2407.SA2 1	3.2939000	3.3089616	Acti 🖌		
Group $4_{\text{linear}}^{\Delta K/K:}$ 0.05 \div e-5/cell, quadr 0.00 \div e-5/cell, starting at 0 \div	U40.2413.SA2 1	3.2852001	3.3025088	Acti 🗹		
Group 5 ^{ΔK/K:} 0.05 + e-5/cell, quadr 0.00 + e-5/cell, starting at 0 + All active to park	040.2419.SA2 1 👻	3.2765999	3.2956529	ACTI 🗹		

Taper modes

$$K(z) = K_0 \left[1 - a \left(\frac{z - z_0}{L_w - z_0} \right)^b \right]$$

Where z is the position coordinate along the undulator system, K_0 the initial undulator strength, z_0 the location where the undulator starts to be tapered, L_w the undulator length, a the fractional tapering at the end of undulator and is *b* the taper changing rate.

b=1 -> linar mode; b=2 -> quadratic mode

$$K(z) = K_0 \left[1 - a_1 \left(\frac{z - z_0}{L_w} \right) - a_2 \left(\frac{z - z_0}{L_w} \right)^2 - a_3 \left(\frac{z - z_0}{L_w} \right)^3 \right]$$

Cubic mode





Possible synchronization scenario

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taper mode

Axis synchronization at nominal speed



Axis synchronization for 4 undulator motors at nominal operation speed ~1mm/s

Positioning accuracy ~ 100nm



European XFEL

Axis synchronization at low speed



Speed ~0.8nm/s, encoders feedback, delta gap =0.1mm

Positioning accuracy ~ 100nm

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Conclusion

Proof of principal shows, that stable operation for a distributed system is possible with 2ms delay between the exchanged timestamps

For the maximal required speed 100μm/s this will create a gap following error for 0.2μm

This value is ~10 times less than the limitation to the following error of the gap ~ 3μ m

In the near future, we plan to make verification measurements on the test setup located in the undulator hall



Thank you for your attention!

