Undulators production and commissioning for the European XFEL

Suren Karabekyan

Argonne National Laboratory

October 14th, 2019

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

- Possible synchronization scenarios

- Requirements
  - Following Error
  - Speed limitation
  - Operation modes
- 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
a	3.10487	3.2143
b	-4.24914	-4.62305
c	0.80266	0.92541

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

$$\frac{\Delta B}{B} = \frac{\Delta K}{K} = \Delta g \cdot \left\{\frac{b}{\lambda} + 2c\frac{g}{\lambda^2}\right\} \leq \rho \quad \rightarrow \quad \Delta g = \frac{\rho}{\frac{b}{\lambda} + 2c\frac{g}{\lambda^2}}$$

ρ is FEL (Pierce) parameter

	λ [mm]	Gap Range [mm]	ρ
SASE1/2	**40**	**10 - 20**	$\leq 3 \cdot 10^{-4}$
SASE 3	**68**	**10 - 68**	$\leq 10^{-3}$

SASE1/2 Gap [mm]	Δg [μm]
10	**-3.1**
20	**-3.5**

SASE3 Gap [mm]	Δg [μm]
10	**-16**
25	**-17**

Following Error
Possible scenarios:

- $\Delta g < 3.1\mu m$
  Fullfils $\rho<3 \times 10\text{-}3$ for SASE1-3;
  Full lasing 'On the Fly'
- $\Delta g > 3.1\mu m$ to $\Delta g <\approx 6\mu m$; $\rho<\approx 6 \times 10\text{-}3$
  SASE1/2 Lasing with reduced performance;
  SASE3 OK
- $\Delta g > 6\mu m$ to $\Delta g <\approx 16\mu m$; $\rho \leq 1 \times 10\text{-}3$
  SASE1/2: Limited to no use
  SASE3: Full lasing 'On the Fly'
- $\Delta g > 16\mu m$ to $\Delta g <\approx 25\mu m$
  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: ≈ 1eV/sec

$$E1[eV] = 2.48311 \cdot 10^{-4} \frac{\gamma^2}{\lambda \ \ [mm](1{+}0.5K^2)}$$

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

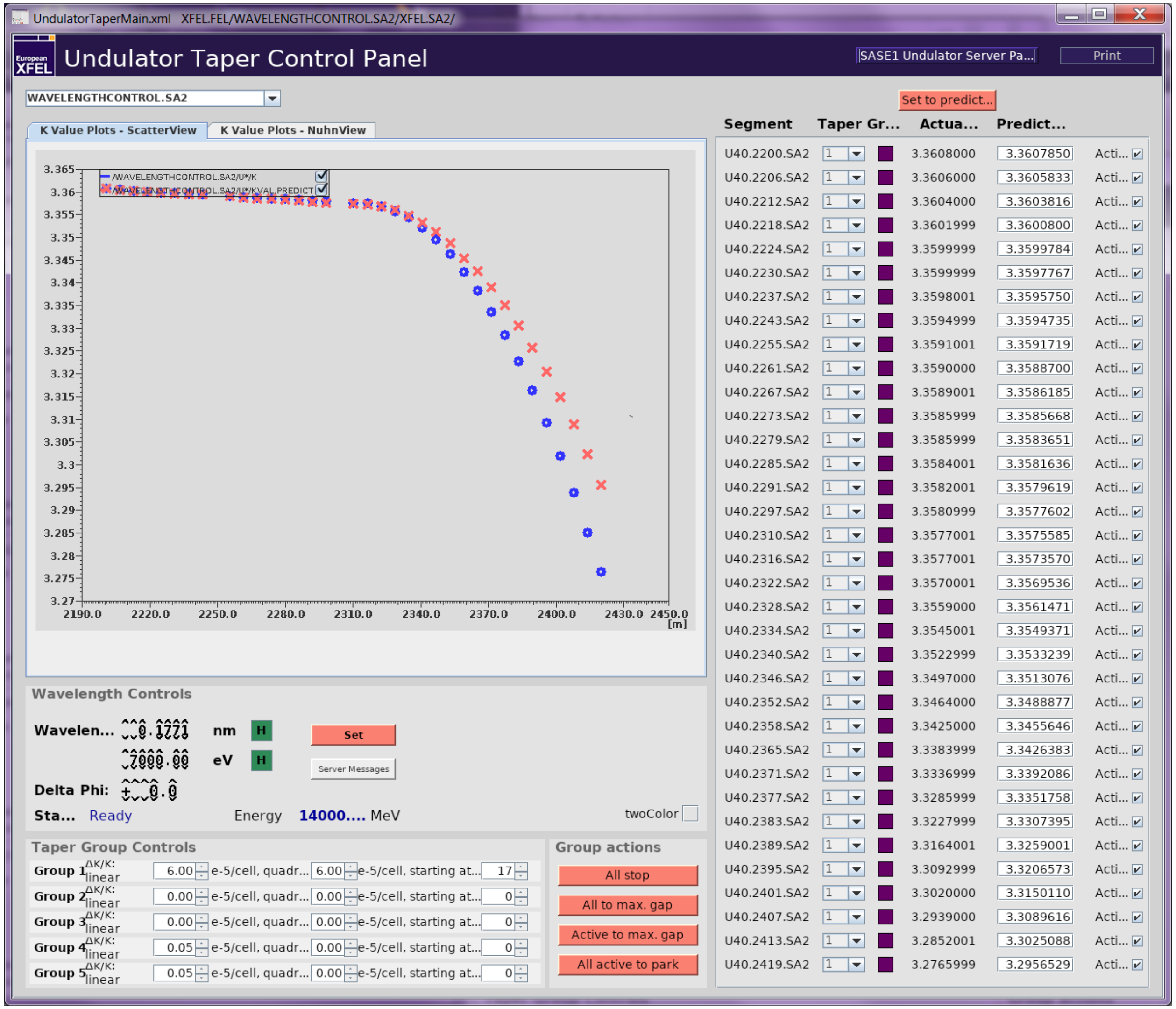
Limitation by Monochromator: ≈ 1eV/sec

	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



Taper modes

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

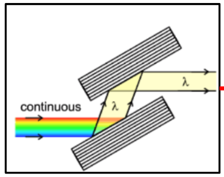
Where z is the position coordinate along the undulator system, K_0 the initial undulator strength, z_0 the location where the undulator starts to be tapered, L_w the undulator length, a the fractional tapering at the end of undulator and is *b* the taper changing rate.

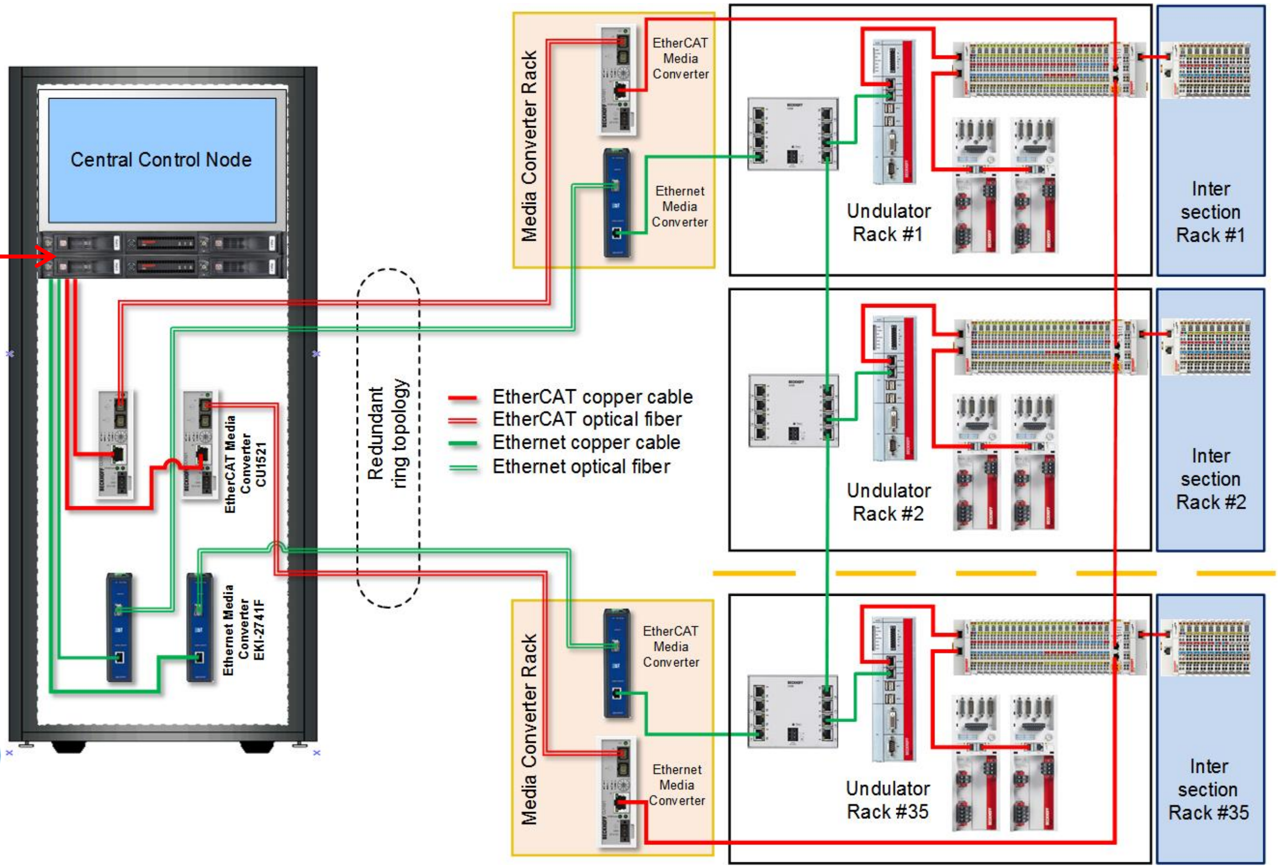
b=1 -> linar mode; b=2 -> quadratic mode

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

Cubic mode

Possible synchronization scenario





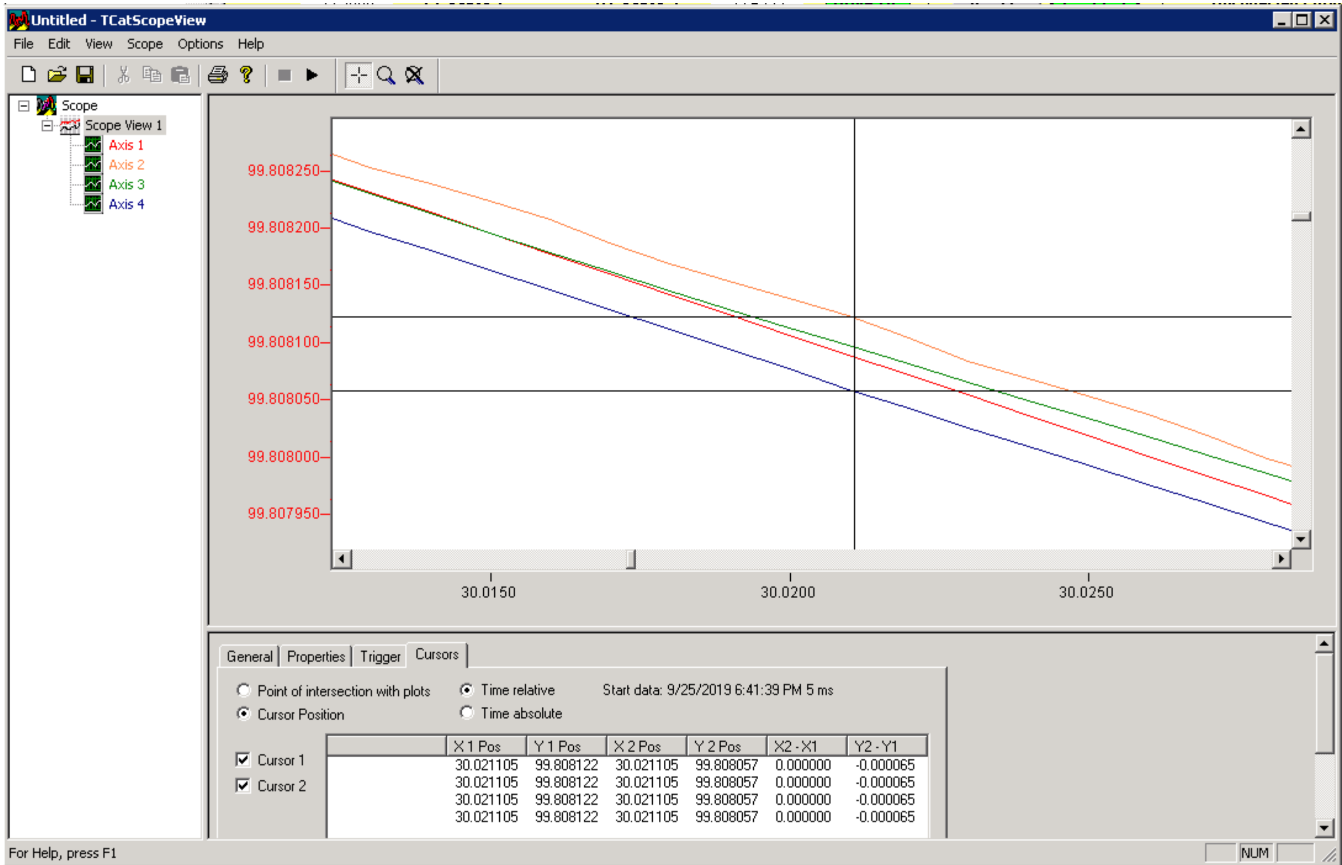
- Monochromator provides selected wavelength λ
- K0 value for the first undulator in the system calculated from the undulator resonance equation:

$$\lambda = \frac{\lambda_u}{2\gamma^2}(1 + K^2/2 + \gamma^2\theta^2)$$

- K(z) values for the further undulators in the
- system is calculated based on the selected taper mode

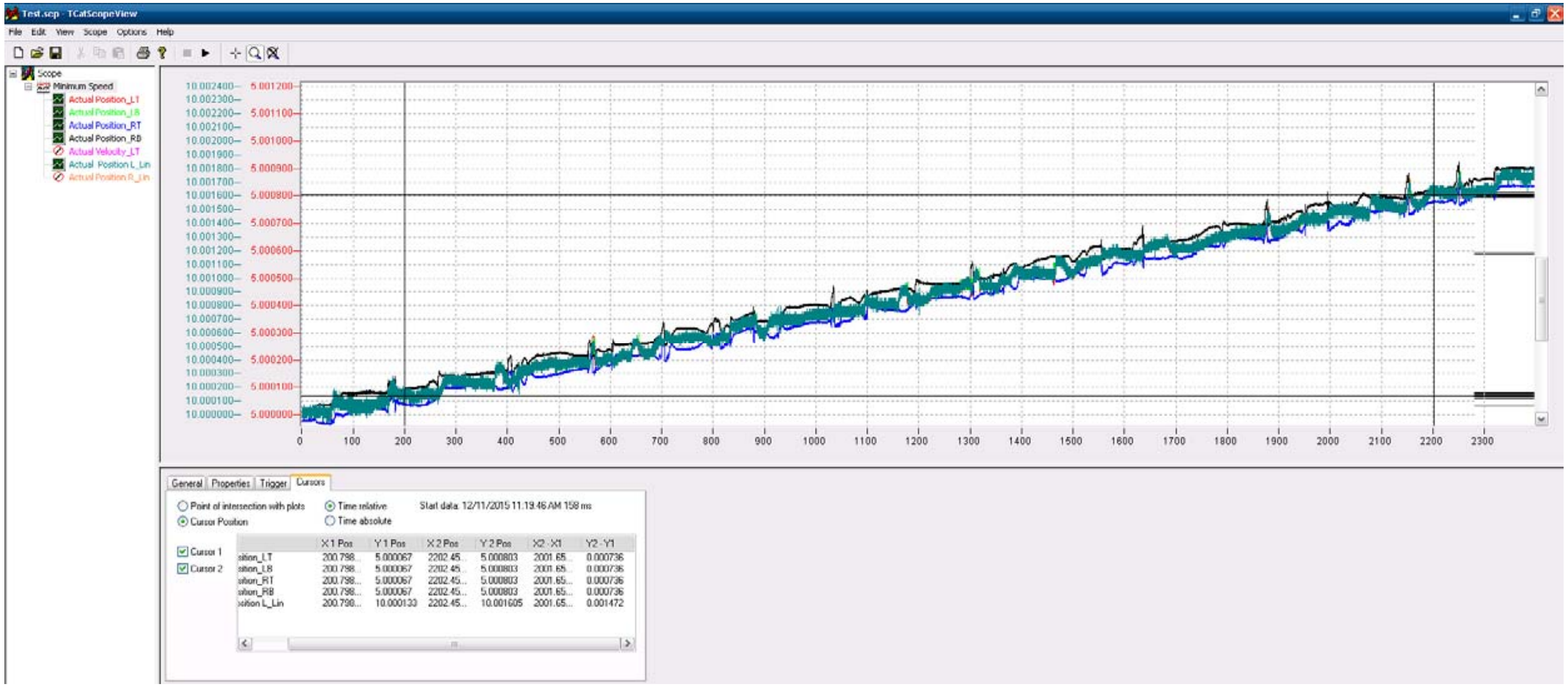
$$K(z) = K_0\left[1 - a\left(\frac{z - z_0}{L_w - z_0}\right)^b\right]$$

Axis synchronization at nominal speed



- Axis synchronization for 4 undulator motors at nominal operation speed ~1mm/s
- Positioning accuracy ~ 100nm

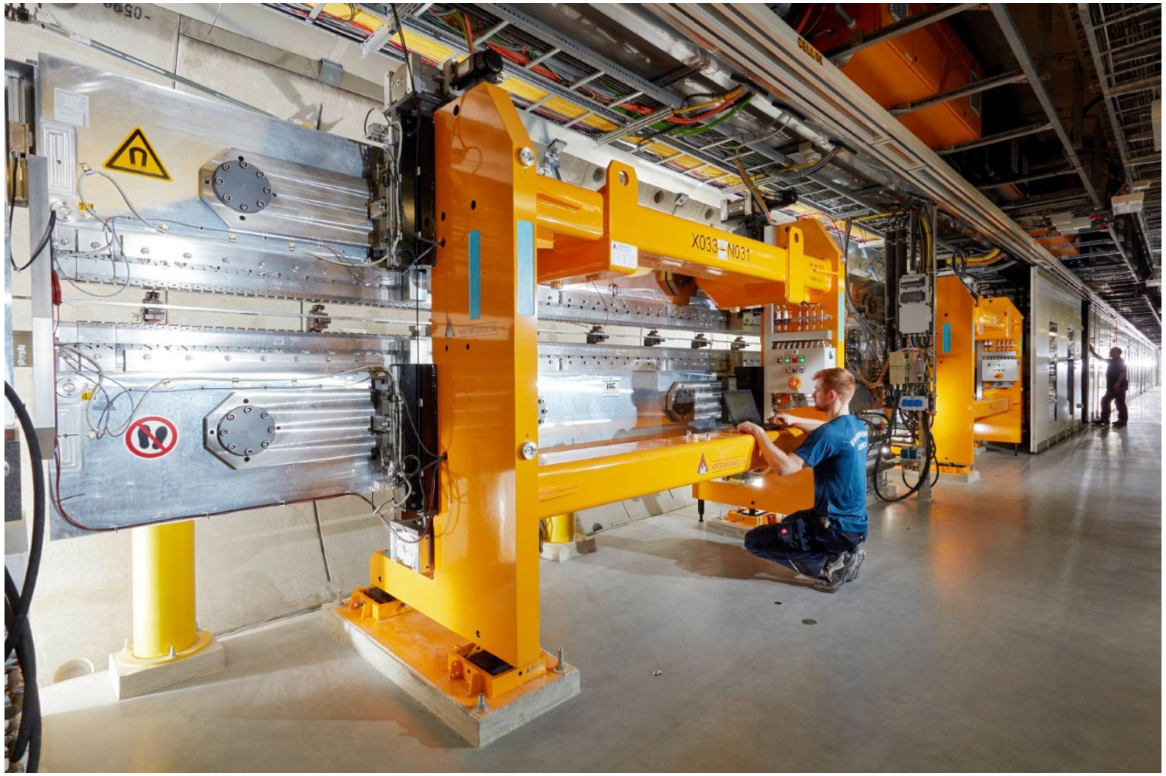
Axis synchronization at low speed



- Speed ~0.8nm/s, encoders feedback, delta gap =0.1mm
- Positioning accuracy ~ 100nm

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 ~ 3µm
- In the near future, we plan to make verification measurements on the test setup located in the undulator hall



Thank you for your attention!