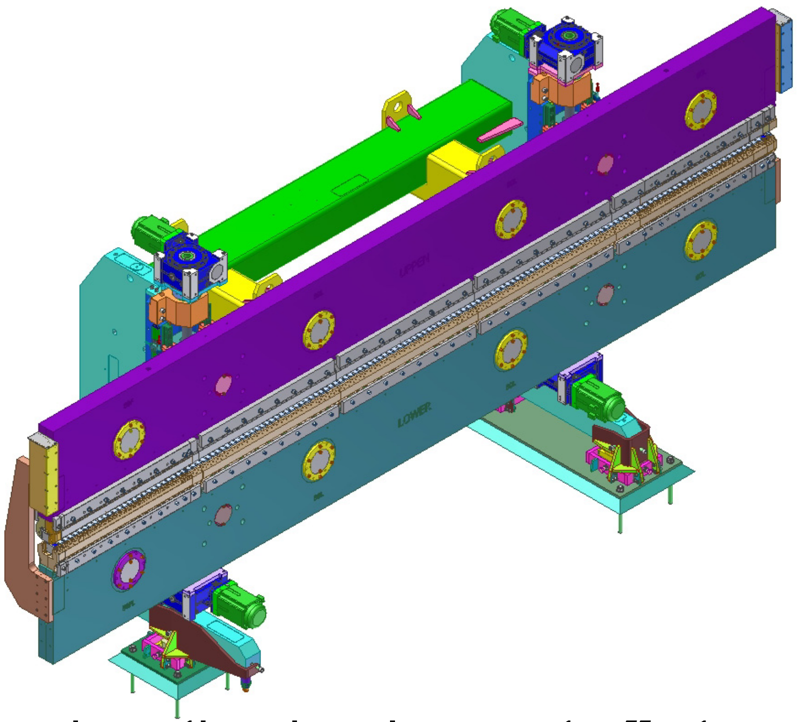
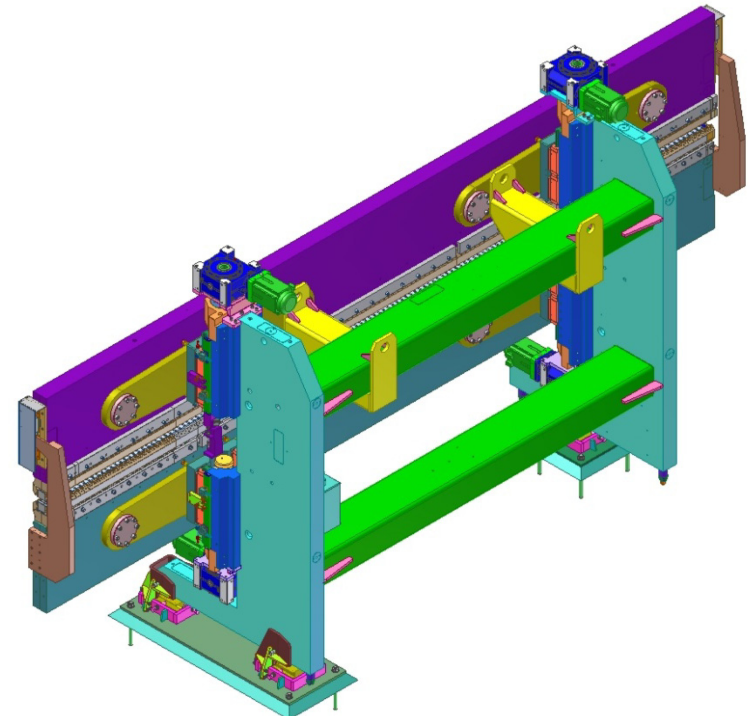
Status Report of PAL-XFEL Undulator Program

D.E. Kim, Y.G. Jung, W,W. Lee, H.S. Kang, I.S. Ko, M.H. Cho,
H.G. Lee, S.B. Lee, , B.G Oh, H.S Suh, K.H Park (PAL, POSTECH)
Suren Karabekyan, Joachim Pflueger (EU-XFEL)

26 Aug. 2015
FEL 2015, Daejeon, Korea

PAL-XFEL Undulator Status



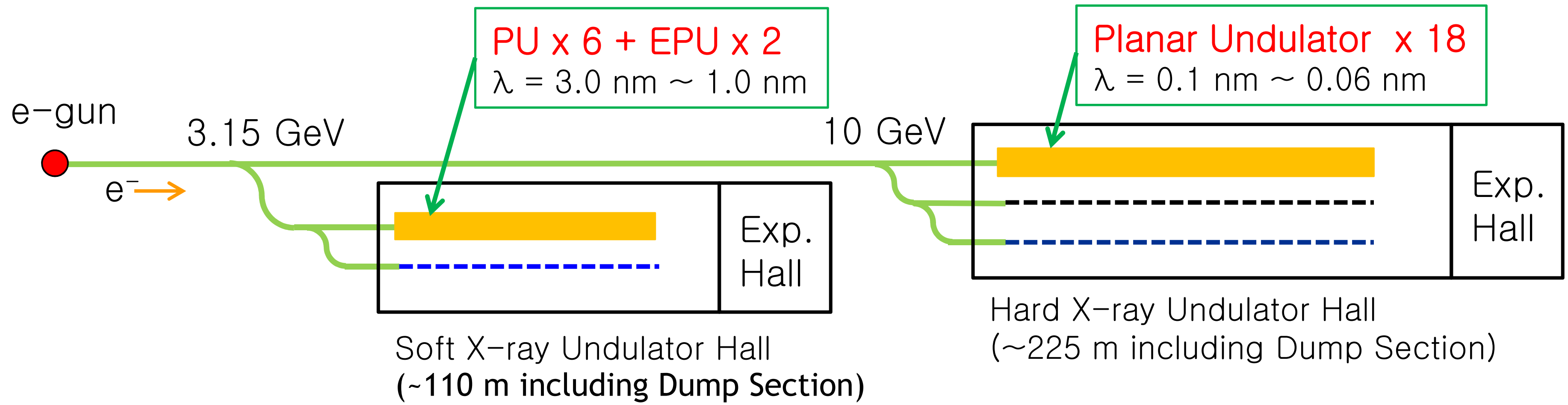


- To reduce the development efforts and period, EU-XFEL undulator design is benchmarked. A MOU to use the EU-XFEL design is agreed on 2011 June between PAL and EU-XFEL.
- The design is proved in FLASH, and PETRA, and it’s cost effective and adapted for mass serial production.
- PAL modification includes, new magnetic design, EPICS IOC, updated tolerances reflecting new parameters.
- Application of tilt-meter for extra safety, “local” touch screen for easy maintenance.

Current Status

- Contract for 18 units of HXU magnetic structure is awarded on Dec 2013. Delivery of the serially produced HXU undulator is started on April 2015. Upto now, 10 HXU undulators are delivered.
- SXU mechanical structure contract awarded to a local company. Expected delivery is at the end of 2015.
- Magnetic measurement and pole height tunings procedures became a routine and approximately 1 undulators are processed per 2 bench-week.
- Two 7m long benchs are in operation.
- Upto now, 10 HXU undulators are assembled and 7 undulators are ready to install, 2 undulators are installed at the undulator Hall.
- Schedule is to install all 18 undulators at the undulator hall in 2015.
- Assembly of all 6 SXU also should complete in 2015.

PAL-XFEL Undulator Layout (Schematic)



- Two FEL beamlines in the first phase: one soft X-ray (SXFEL1) and one hard X-ray (HXFEL1)
- **Planar Undulator + EPUs** in soft x-ray FEL provides the capability of **full polarization control**

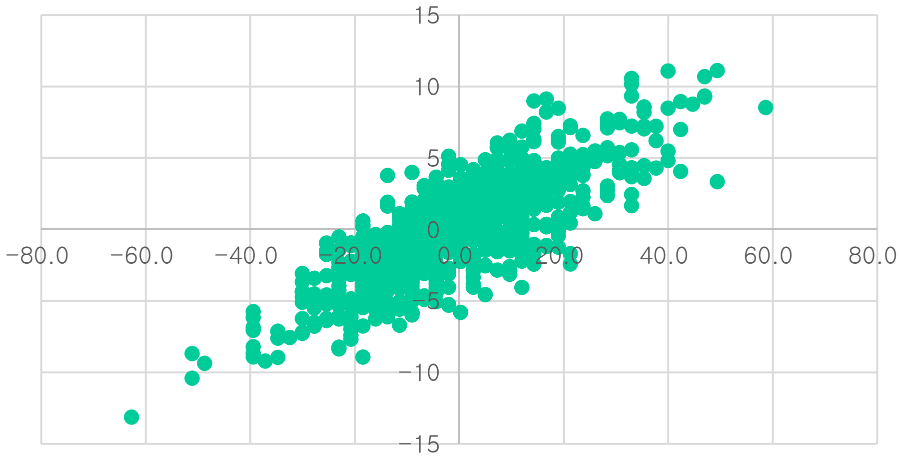
XFEL	HXFEL1	SXFEL1
Beam Energy [GeV]	10.0	3.15
Wavelength [nm]	0.7 ~ 0.06	3.0 ~ 1 .0
Wavelength tuning	Beam energy: 0.7 ~ 0.1 Gap change : 0.1 ~ 0.06	Undulator gap
Undulator type	Planar	Planar+EPUs
Undulator period [cm]	2.6	3.5
Undulator gap [mm]	8.3	8.3

Basic Undulator Parameters of PAL-XFEL

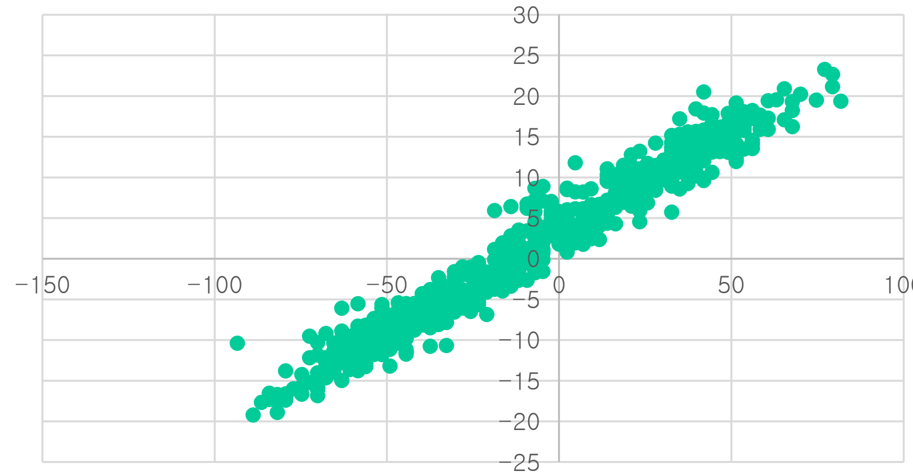
	Unit	HX min gap	HX max gap	SX min gap	SX max gap
E	GeV	10.000	10.000	3.150	3.150
g	mm	8.30	11.39	8.3	15.0
λ_u	mm	26.0	26.0	35.0	35.0
I_p	A	3000	3000	2500	2500
λ_r	nm	0.1000	0.0600	3.0000	1.0000
ε_n	mm mrad	0.5	0.5	0.5	0.5
β_X	m	20.0	20.0	12.0	12.0
β_Y	m	20.0	20.0	12.0	12.0
σ_e	Unitless	1.00E-04	1.00E-04	3.17E-04	3.17E-04
Lg	m	3.14	5.69	1.03	1.63
Lg/Lg1D	Unitless	1.32	1.85	1.22	1.24
Pbeam	TWatt	30.0	30.0	7.9	7.9
Psat	GWatt	13.8	5.5	17.0	10.6
Lsat	m	58.0	99.6	21.1	32.2
K	Unitless	1.9727	1.2390	3.3209	1.5306
B_{eff}	Tesla	0.8124	0.5102	1.0159	0.4682

Correlation btw Supplier and PAL Measurements

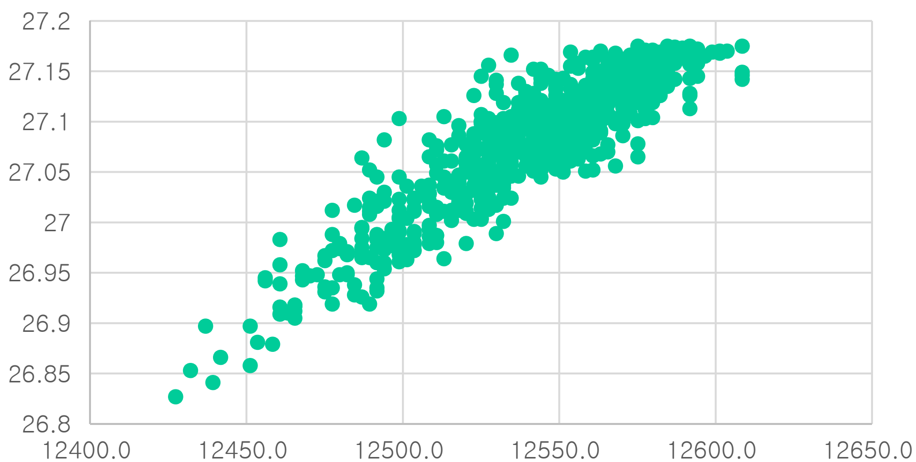
Mx Correlation



My Correlation



Mz Correlation

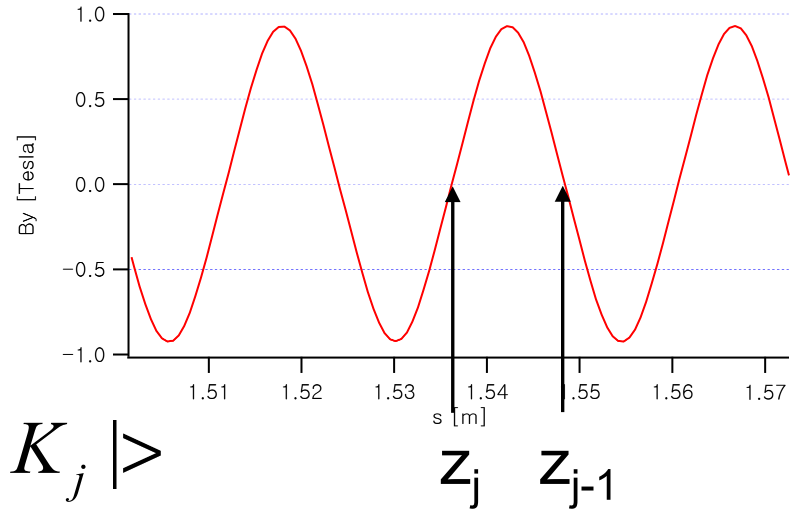


- Mostly shows good correlation between PAL and the supplier measurement.
- Result is affected by the temperature stability of the measurement room.

Local K correction*

Definition of local K_j: $K_j = \frac{2e}{mc}\int_{z_{j-1}}^{z_j} B_y(z)\,dz$

z_j is the zeros of the field profiles



Deviation from ideal K: $\Delta K_j = K_j \pm \langle |K_j| \rangle$

Impact of the j-th pole tuning from all other poles: $\Delta K_i = \sum_{j=1}^{N} a_{ij}\Delta p_j$

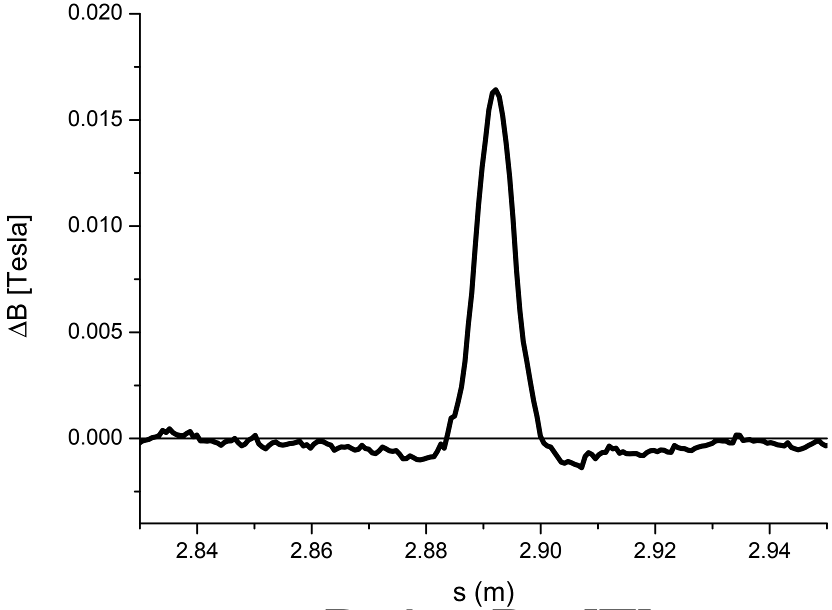
a_{ij} : local K change of the i-th pole due to j-th pole tuning

Δp_j : gap change of the j-th pole [mm]

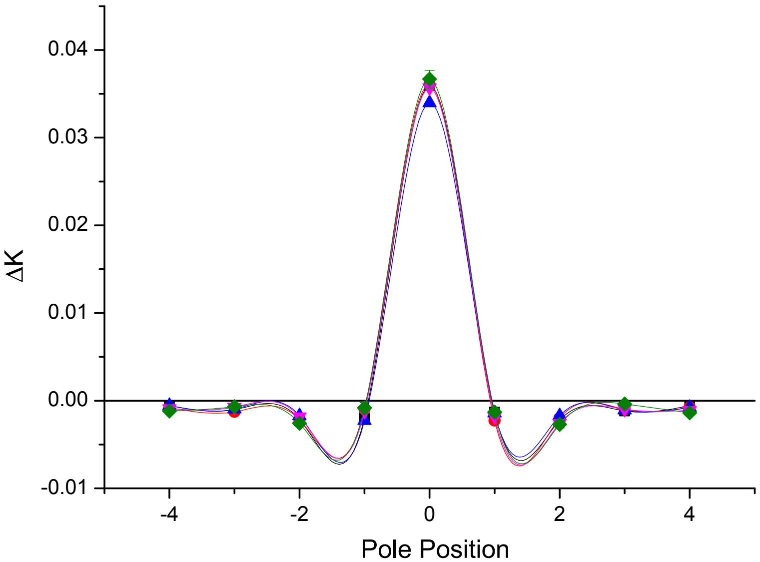
a_{ij} : a_{ij} is diagonally dominant and only 3 off diagonal components are considered.

**Y. Li, J. Pflueger, to be published in Journal of synchrotron Radiation.*

Field Change Due to 100 um Pole Height Change



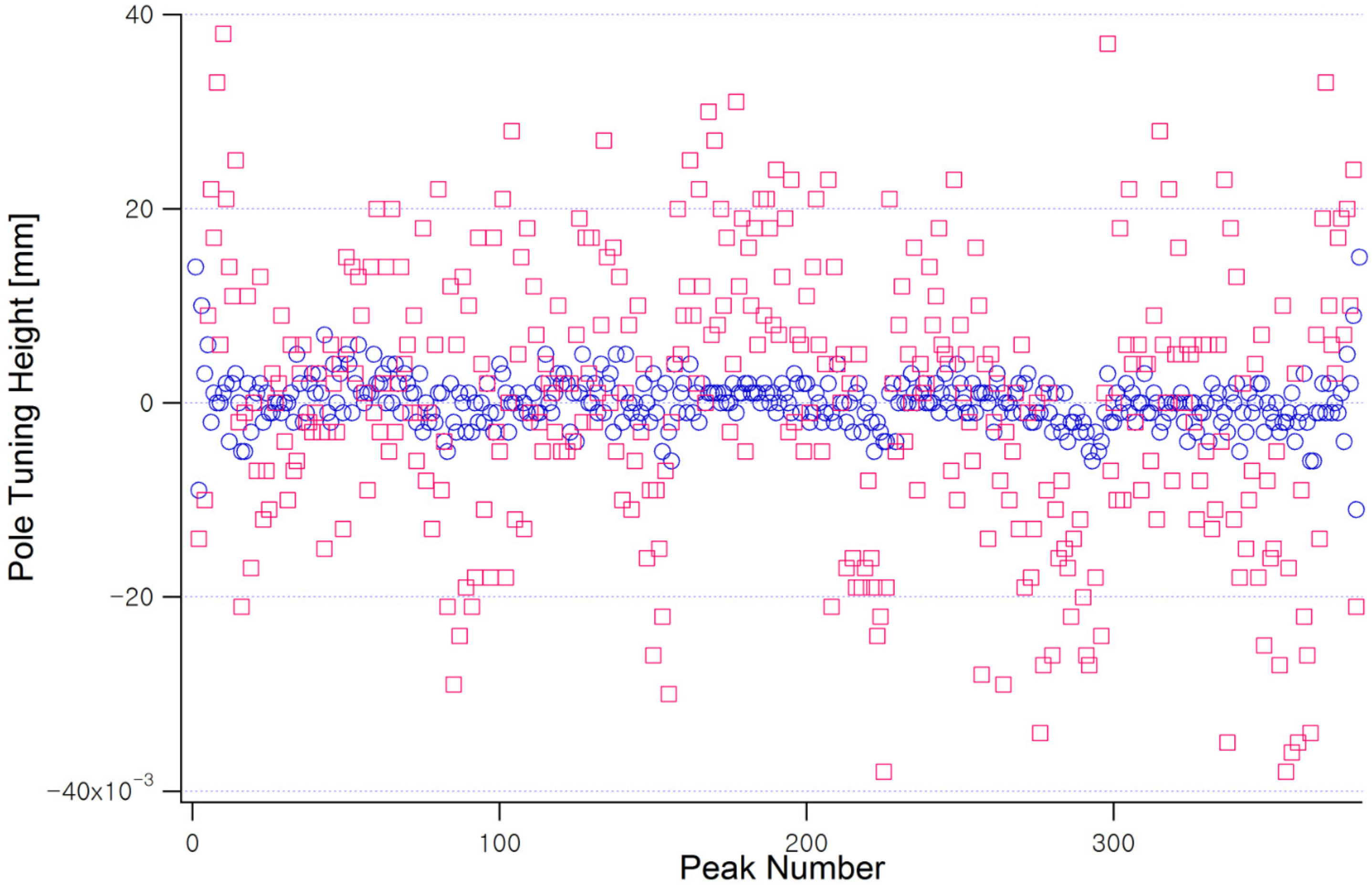
Delta By [T]



Delta K

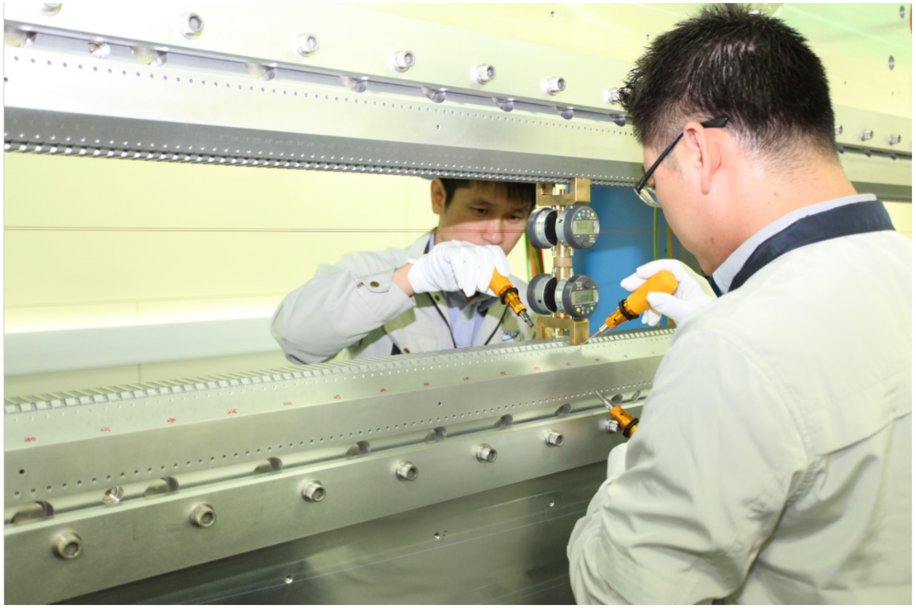
- Pole tuning signature for 100 um at working gap.
- Expected max pole tuning height is about 60 um. Used 100 um to improve S/N ratio of the Signature. Assumed to be linear within the range.
- Left one is the field change and right side is the local K changes.
- Negative impact to the side poles exists although mostly diagonally dominant.
- Measured at 5 independent positions and the data are averaged, and symmetrized to get the matrix component.

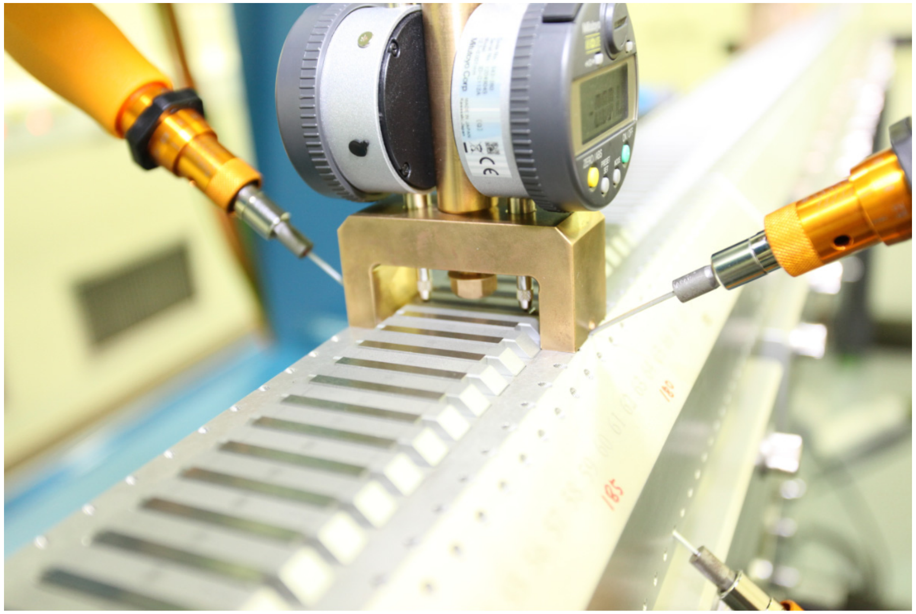
Calculated Corrections



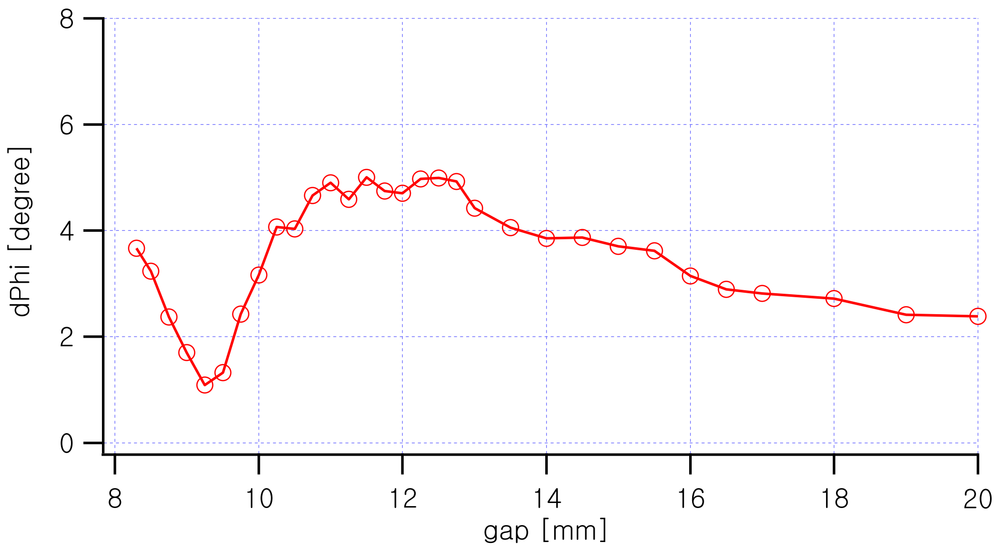
- Red square are required corrections based on the magnetic measurement just after delivery. Phase jitter as delivered is between 10-13 degree
- Blue circles are required corrections based on the magnetic measurement after the 1st pole height tuning. After 1st pole height tuning, phase jitter reduces to 1-2 degrees.

HXU on the measurement bench



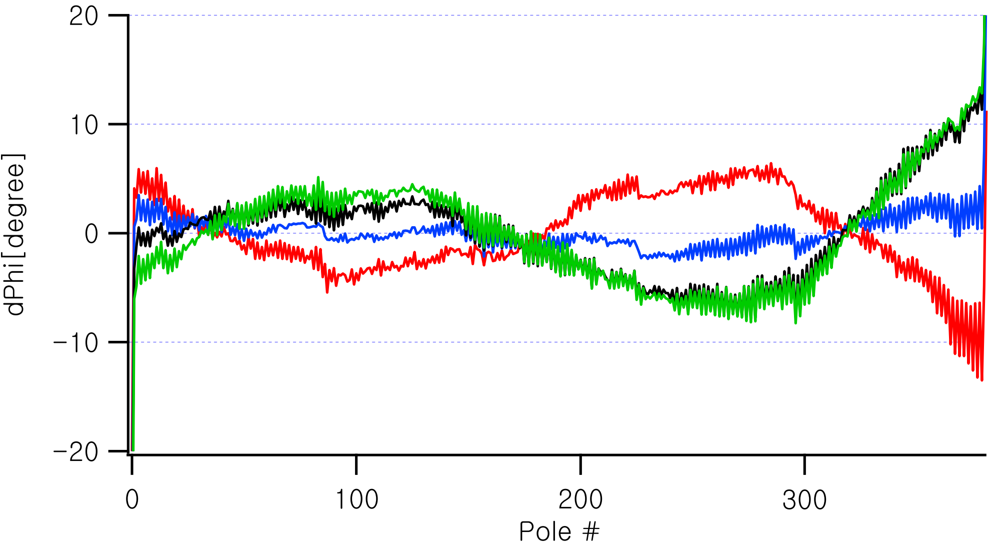


Gap Dependent Phase Jitters

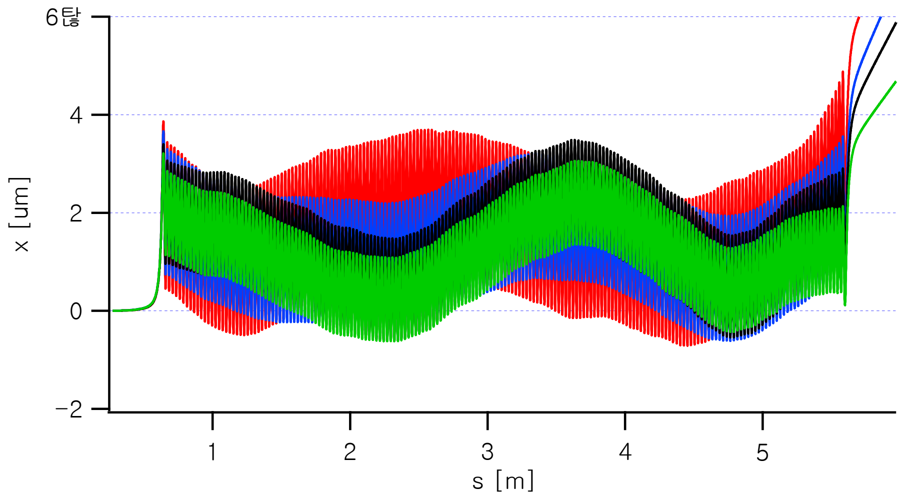


Gap dep phase jitter

When we move away from the "tuning gap", the phase jitter shows typical signature of the small girder bending.

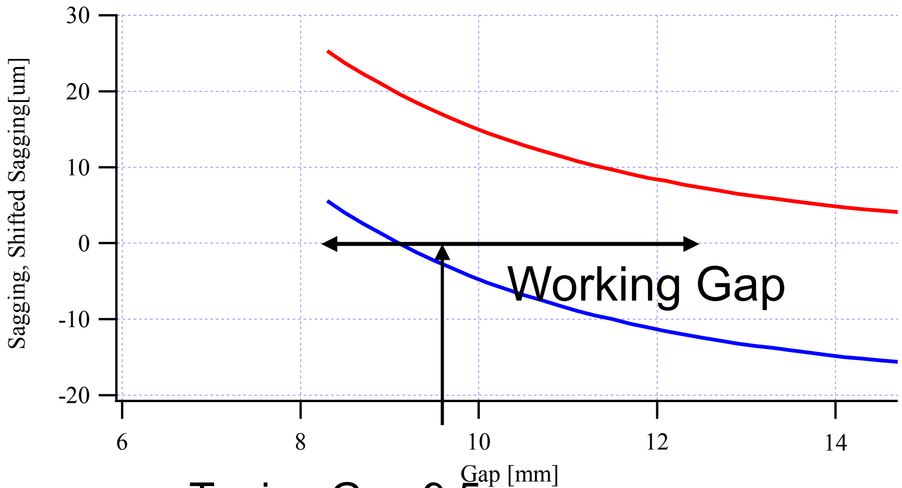


Phase jitter profiles for several gaps

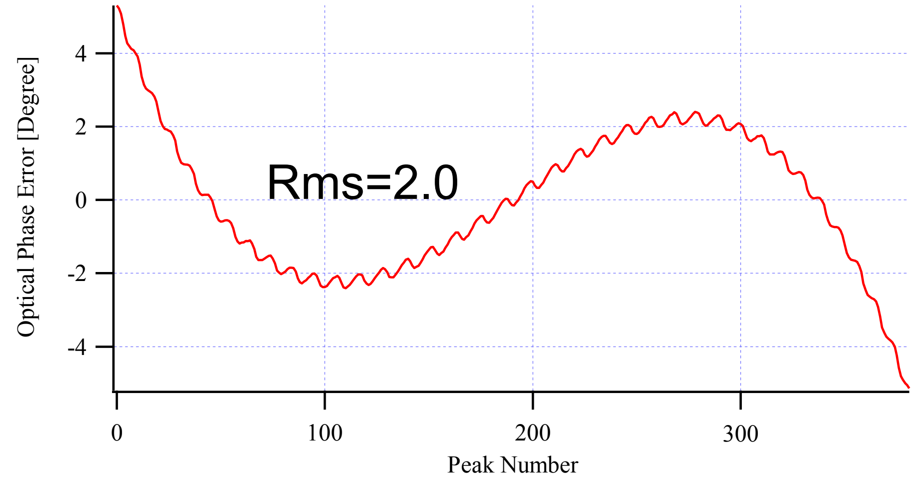


E-orbit for several gaps

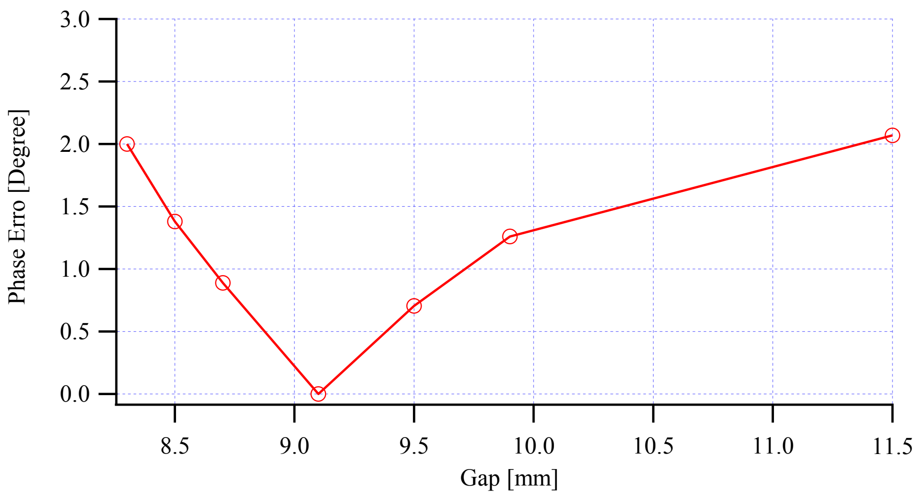
Impact of the Girder Deformation and Tuning Gap



Tuning Gap 9.5 mm



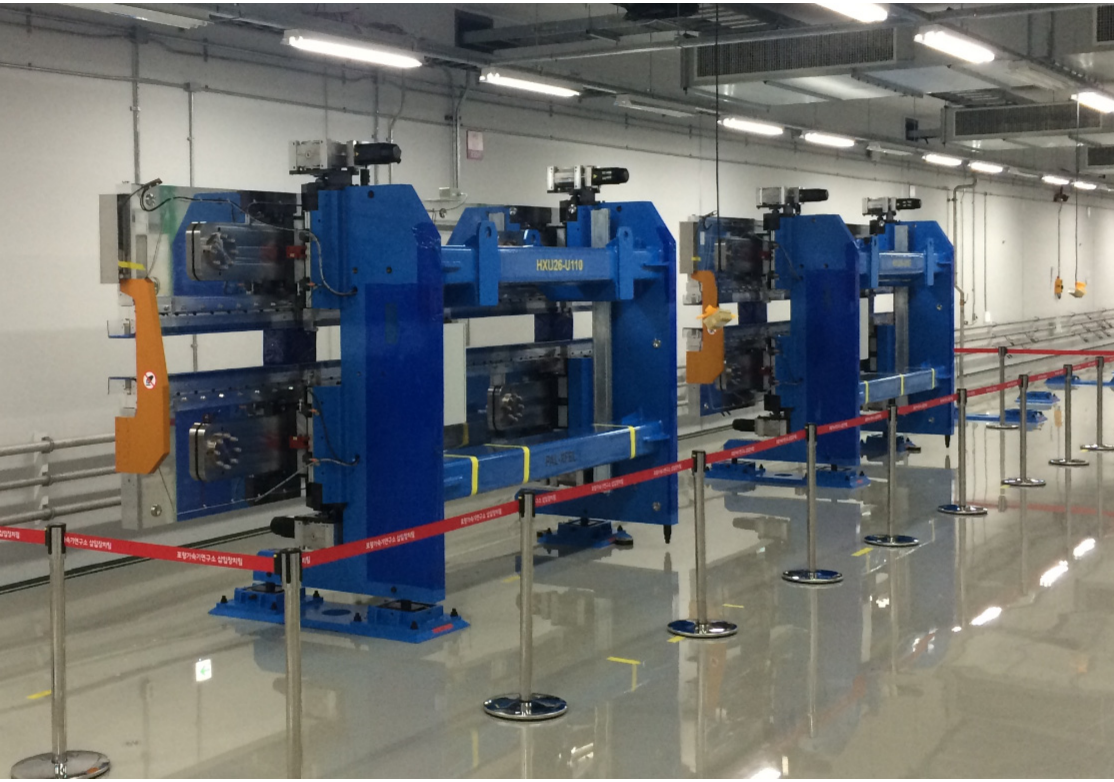
Example of the phase error at min gap due to the girder deformation



Phase error variation of the ideal undulator due to girder deformation

- Girder deformation is estimated for various gaps of U26.
- Tuning gap is determined to have same normalized girder deformation within working gap. (normalized to the gap)
- Field Variation due to the deformation is introduced to the ideal field and the resulting phase error is calculated within the working gap.

Installed Photograph



- 10 HXU Units are assembled.
- 7 are tuned and ready to install (21 Aug 2015)

Issues and Summary (1)

- Different Hall probes has a slight different scaling. (about 4×10^{-4}). Another 3rd party Hall probes (known to have better accuracy) are purchased and used for calibrating the existing hall probes.
- Also, optical K measurement using the undulator spontaneous radiation is planned measurement.
- The company supplied "Moving wire" system which uses direct integration was not precise enough. We had to modify it to use analogue integrator for better accuracy and reproducibility.
- The moving wire system is fine calibrated using a small "standard magnet" with known field integral with broad "good field region".
- The field integral data from Hall probe was not precise enough (planar hall effect, impact of even order calibration error), and moving wire integral measurement is used to tune the Hall scan data.

Issues and Summary (2)

- EU-XFEL undulator system is successfully modified for PAL-XFEL undulator system including magnetic structure, EPICs implementation of the control system.
- 18 HXU undulator installation is scheduled to be finish on Dec 2015.
- 6 SXU undulator assembly and magnetic measurement is scheduled to finish within Dec 2015.
- The matrix formulation of the pole height tuning scheme works very good. The measurement and correction is now routine procedure and all data are tabulated including Keff, phase jitter, required initial Kick, exit Kicks for all working gaps.
- 10 HXU assembled, 7 HXU tuning completed, 2 installed.

- Tight schedule of installation is a BIG challenge.
  - Thank you so much for your attention!