PAL-XFEL

HB2018 THA2WD03

Real-Time Measurement of Fluctuations of Building Floor and Installed Devices of Large Scientific Equipment

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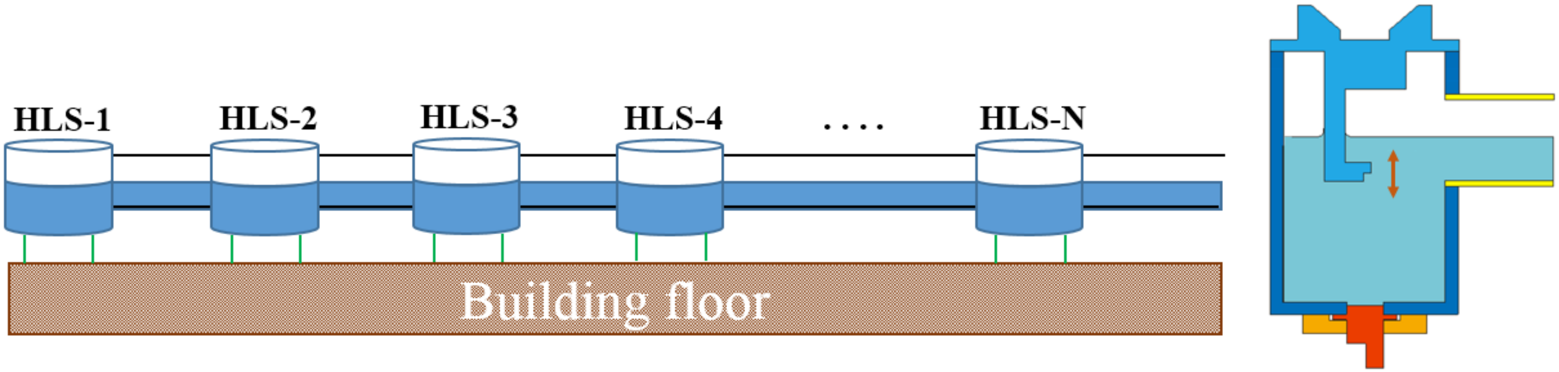
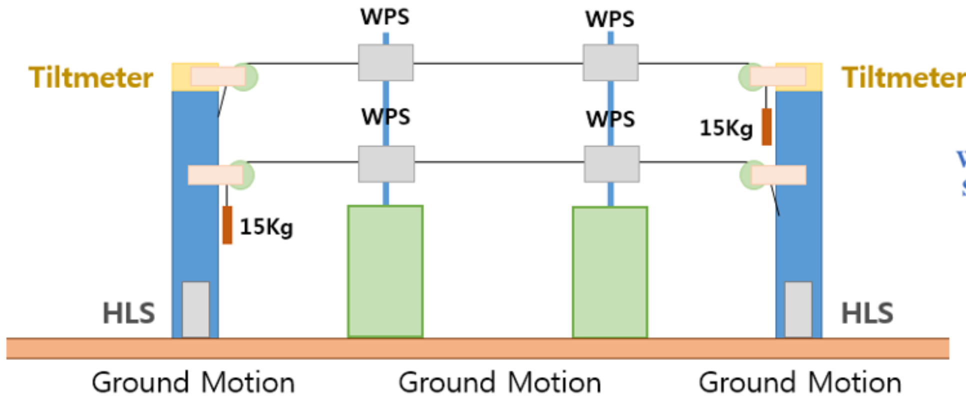
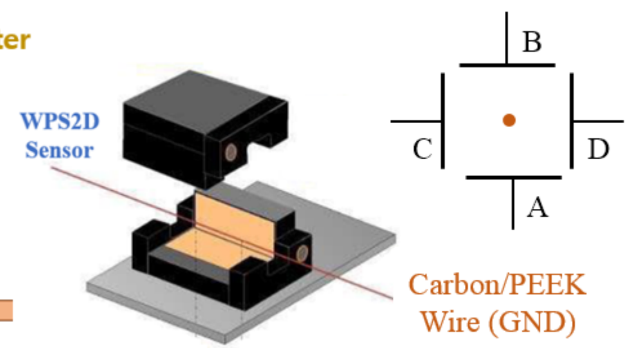
Several parts that comprise the large scientific equipment should be installed and operated at precise three-dimensional location coordinates X, Y, and Z through survey and alignment to ensure their optimal performance. As time goes by, however, the ground goes through uplift and subsidence, which consequently changes the coordinates of installed components and leads to alignment errors ΔX, ΔY, and ΔZ. As a result, the system parameters change, and the performance of the large scientific equipment deteriorates accordingly. Measuring the change in locations of systems comprising the large scientific equipment in real-time would make it possible to predict alignment errors, locate any region with greater changes, realign components in the region fast, and shorten the time of survey and realignment.

① Hydrostatic Leveling Sensor (HLS) System : Survey the Building floor



② Wire Position Sensor (WPS) System : 2D Survey the Girder and Devices





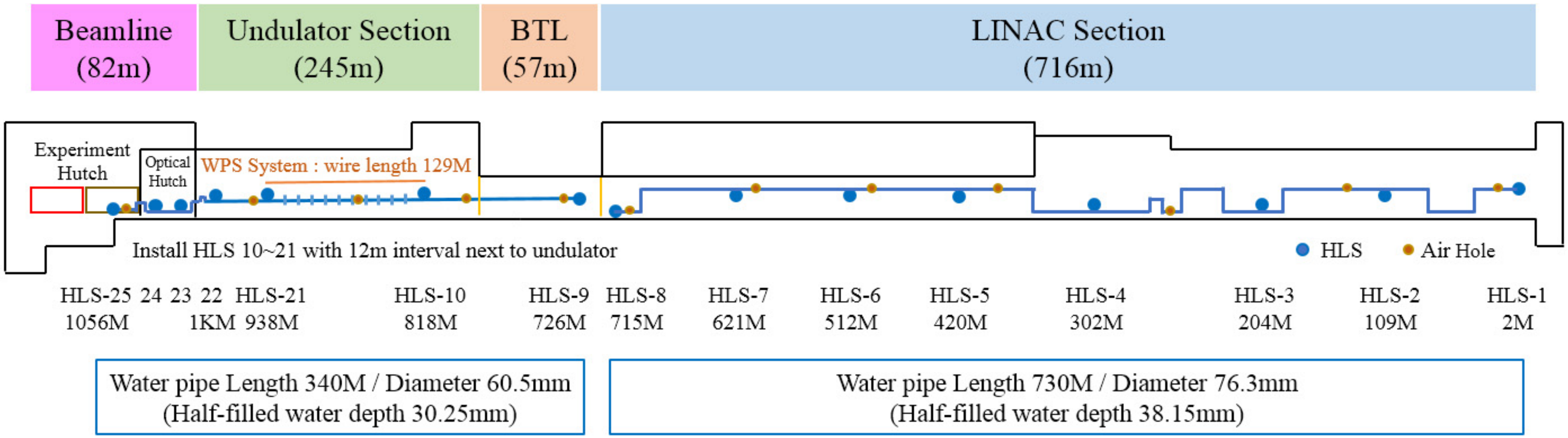
Why install a survey system in a tunnel ?

① **Harmful radiation to the human body.**

② **Area is wide & Takes a long time for a person to do survey work.**

③ **Want to know the location change of floor and equipment in real-time.**

- Especially heavy rains, earthquakes

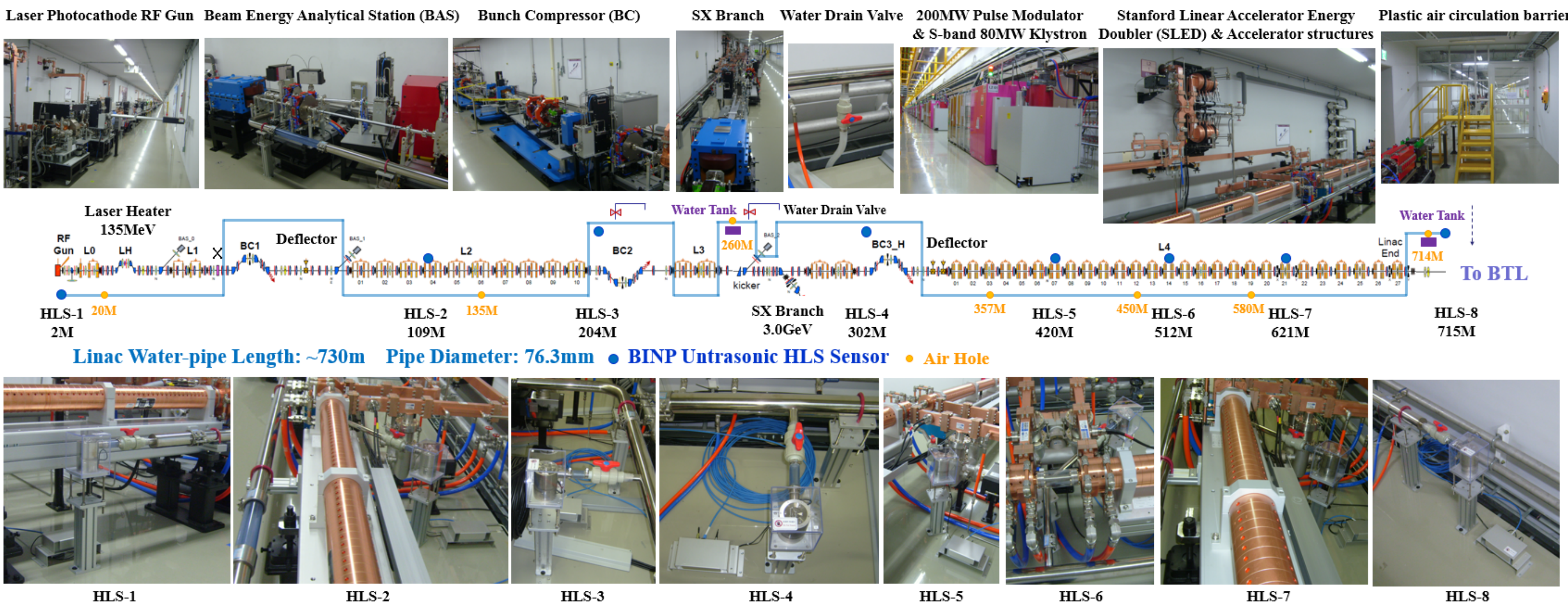


► All components of PAL-XFEL were completely installed in December 2015, and Hard X-ray 0.1nm lasing achieved through its beam commissioning test and machine study on March 16, 2017. The beam line users are use the hard X-ray since March 22, 2017 [1, 2].

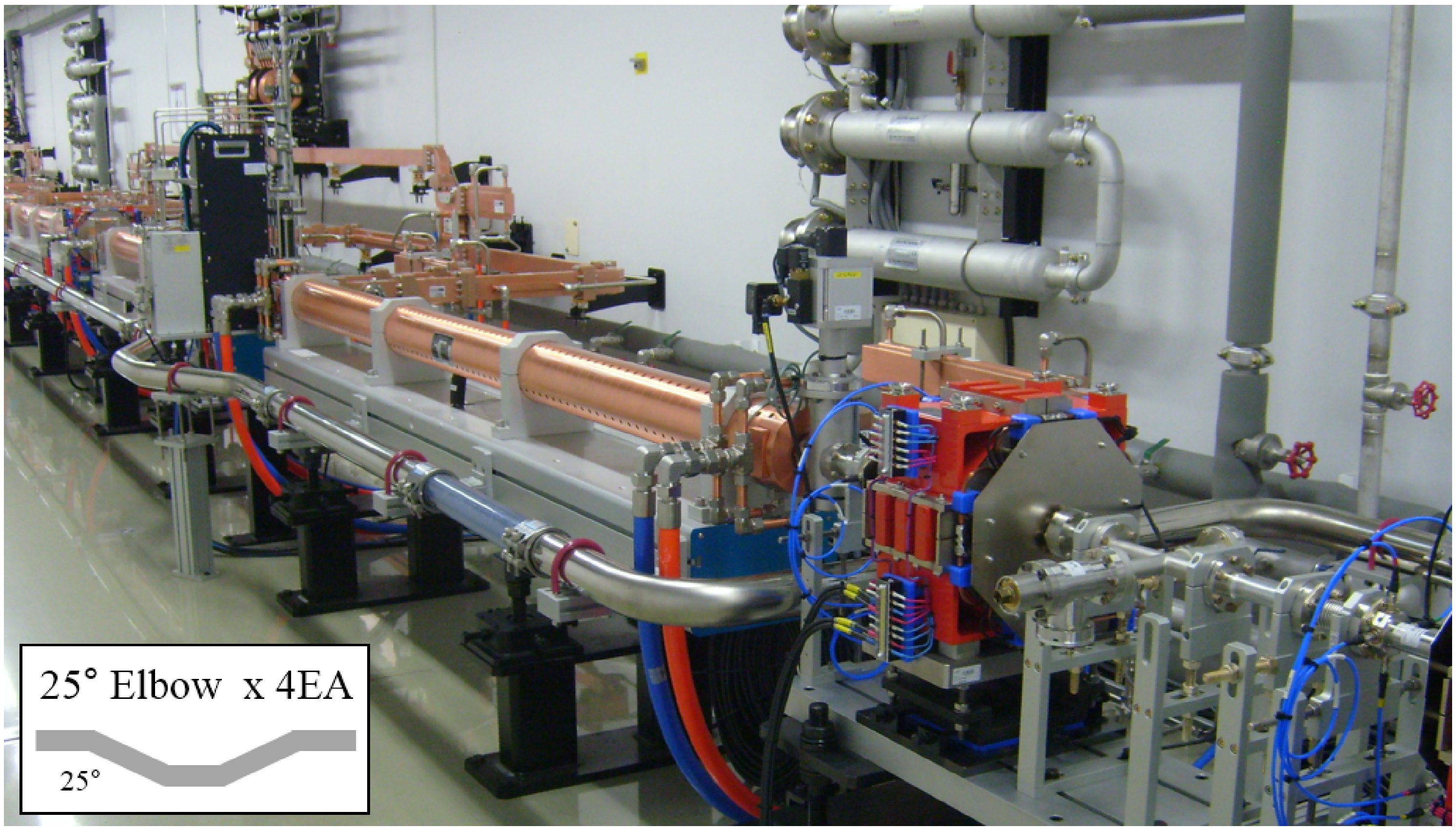
► The HLS and WPS system has been installed since September 2016 to measure and record changes of the building floor and devices in real-time [3].

[1] I.S. Ko et al., "Construction and Commissioning of PAL-XFEL Facility", Applied Science 2017, 7(5), 479. Doi:10.3390/app7050479.
[2] H.-S. Kang et al. "Hard X-ray free-electron laser with femtosecond-scale timing jitter", Nature Photonics, vol. 11, p. 708, 2017. Doi:10.1038/s41566-017-0029-8.
[3] HJ Choi et al., "Wire position system to consistently measure and record the location change of girders follow-ing ground changes", Journal of Physics: Conf. Series 874 (2017) 012088. Doi:10.1088/1742-6596/874/1/012088.

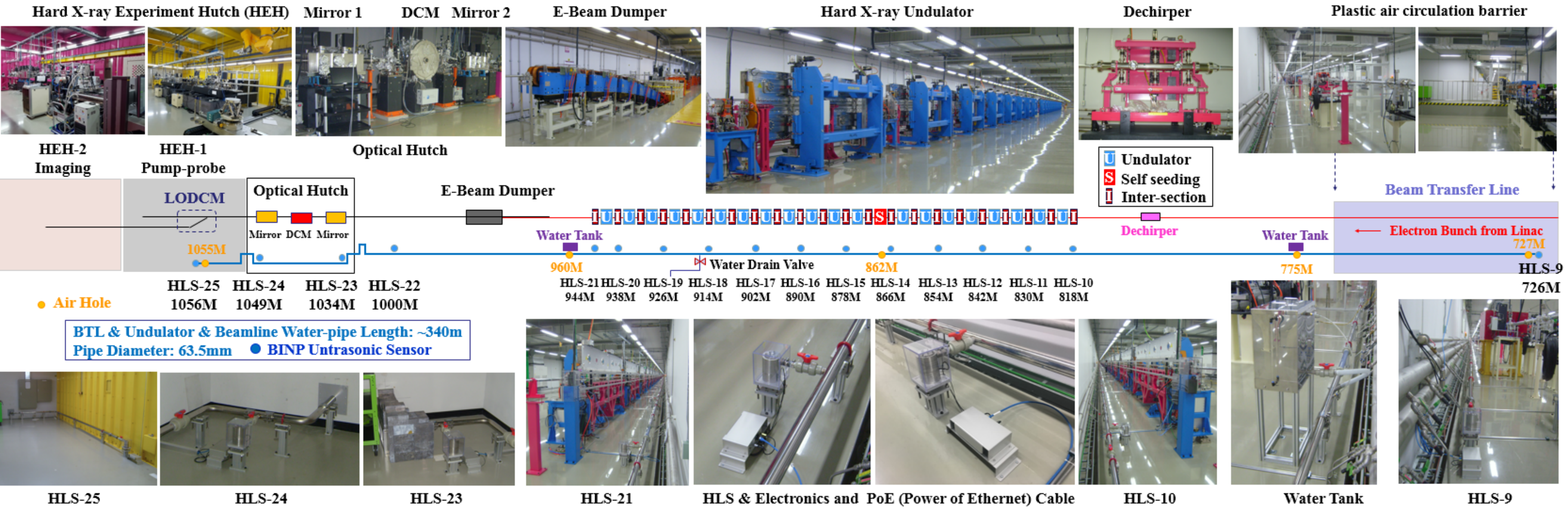
HLS installed in LINAC section



LINAC section use eighteen 90° elbow pipes, twelve 45° elbow pipes and fifty-six 25° elbow pipes.



HLS installed in Undulator section



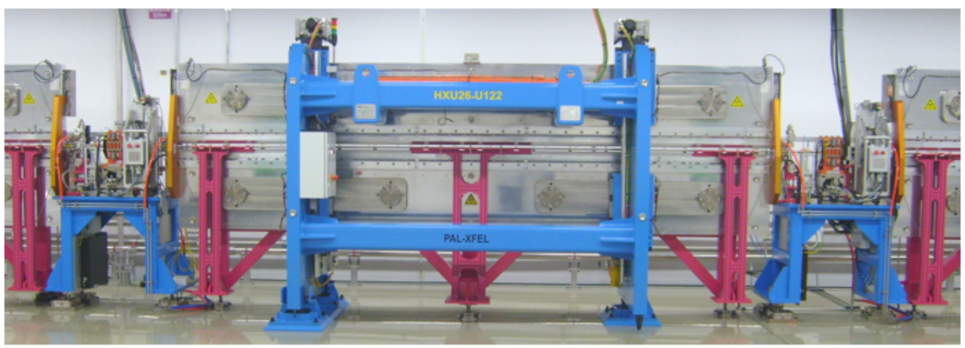
Radiation safety regulations : Radiation shield with a lead block for waterpipe to pass through the walls of the building.

Hyojin Choi et al., “Operation Status of HLS system installed to Measure Ground Change of Large Scientific Equipment in Real-Time”, in Proc. of MEDSI2018, Paris, France, paper WEPH18 (2018).

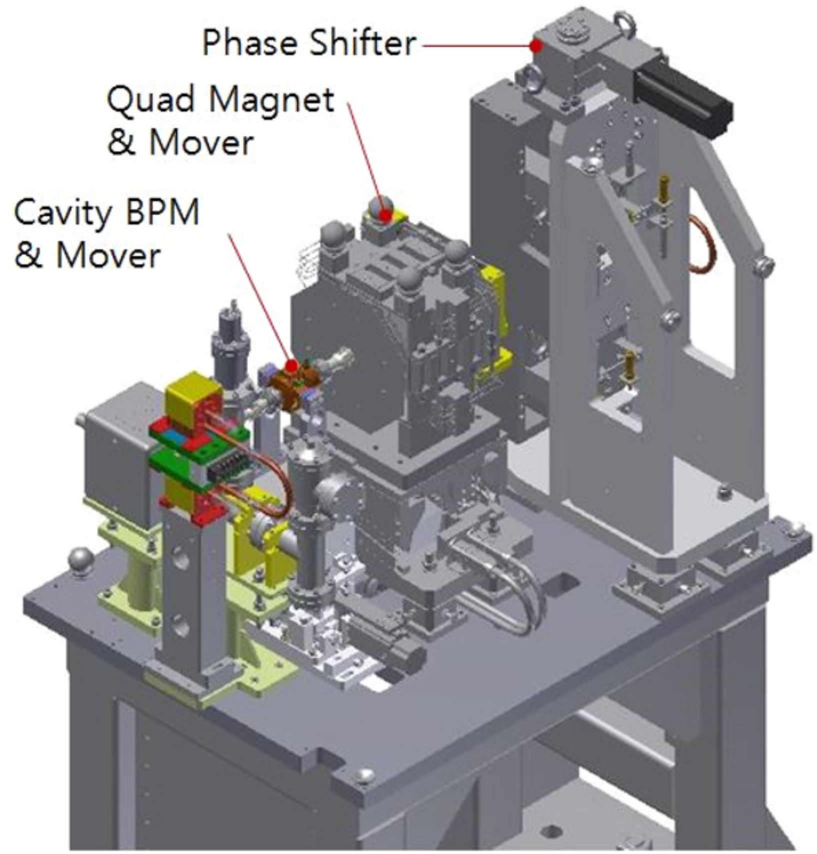
WPS installed in Undulator section

The WPS is installed on all intersection girder with two parallel up and down.

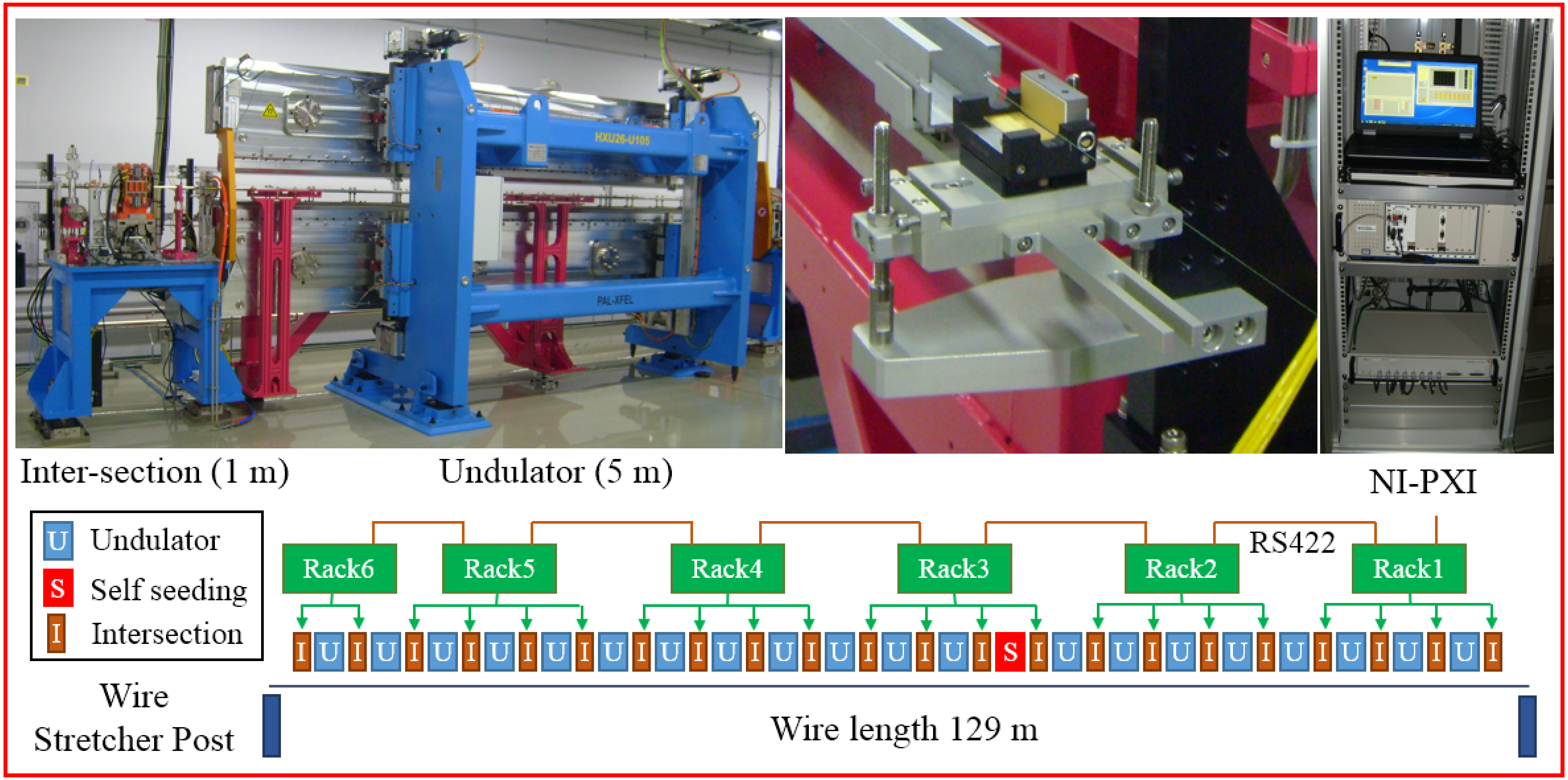
Layout of inter-section



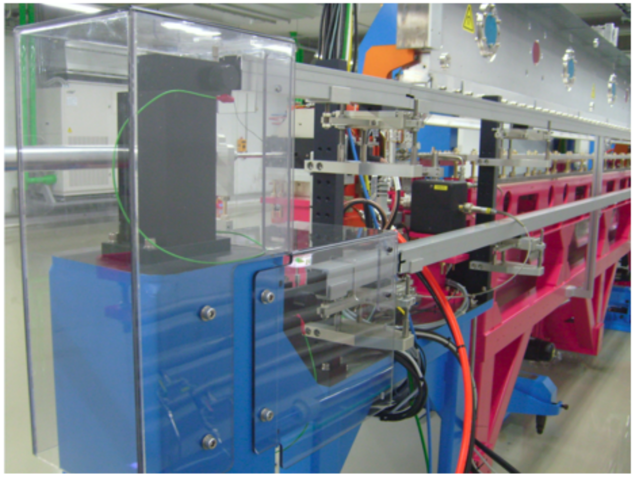
Inter-section Undulator Inter-section



WPS system installation and WPS fixed bracket

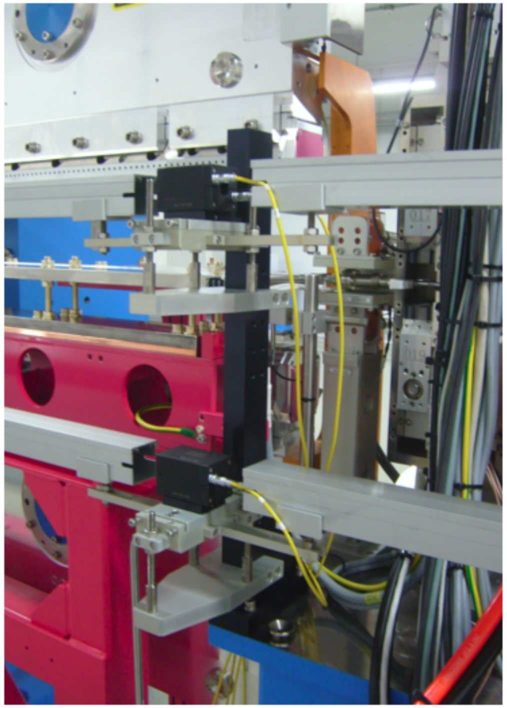


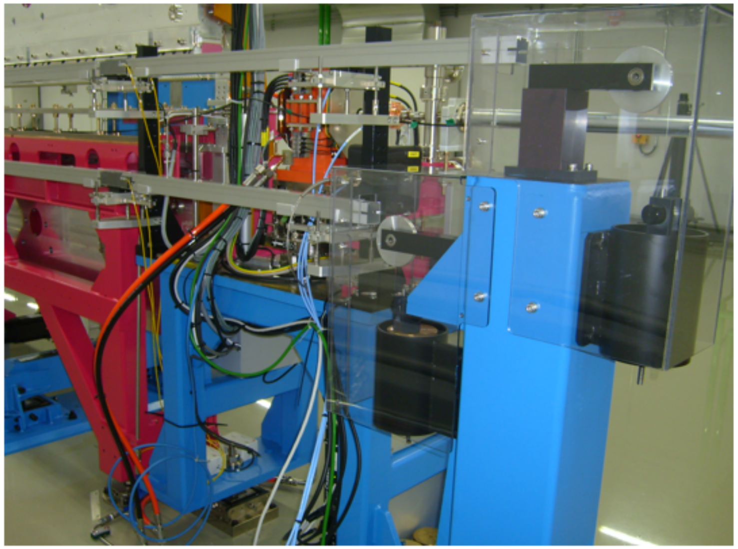
Wire stretched Post and WPS sensor support



Wire Fixed Point
- Protect plastic cover

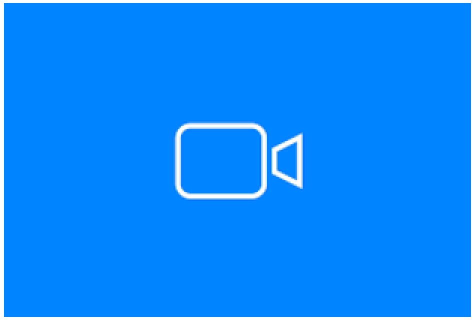
WPS Support & Fixed Bracket
- Wire protect Duct





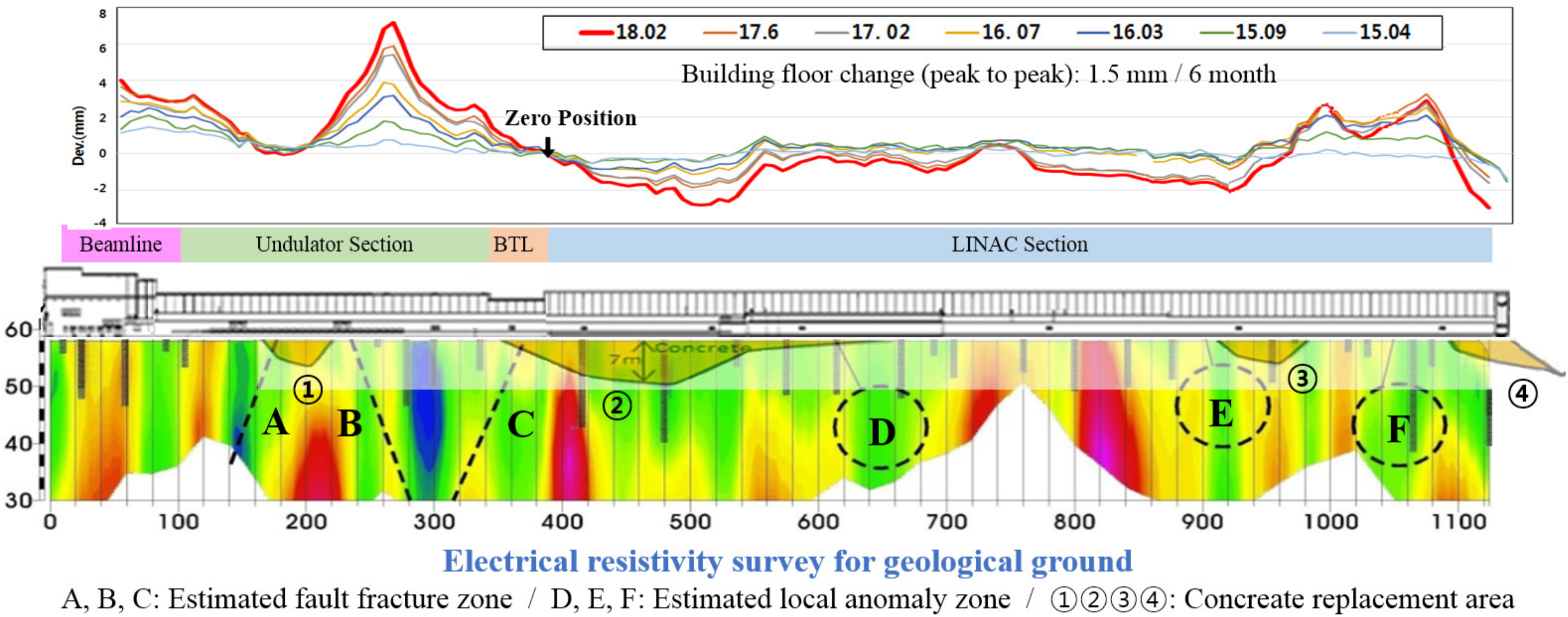
Friction less Pulley
- Counter weight (12~15kg)
- Protect plastic cover

PAL-XFEL Introduction Video (1 min)



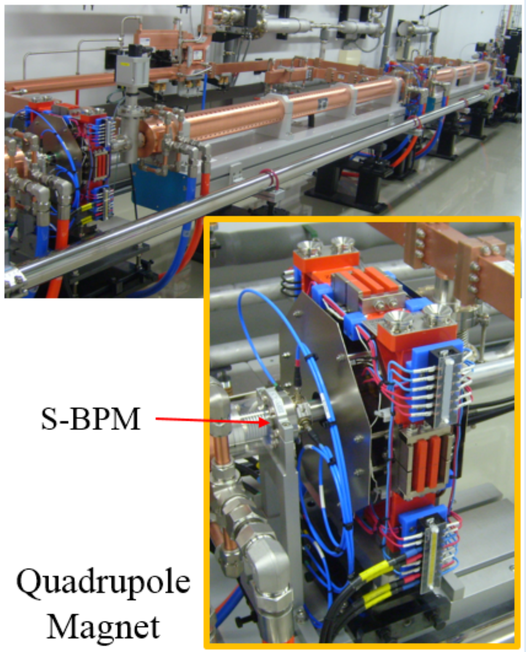
Control Room Screen

Figure 6: PAL-XFEL 지반 구조와 변화



Main Feedback system for beam correction

Linac



S-BPM

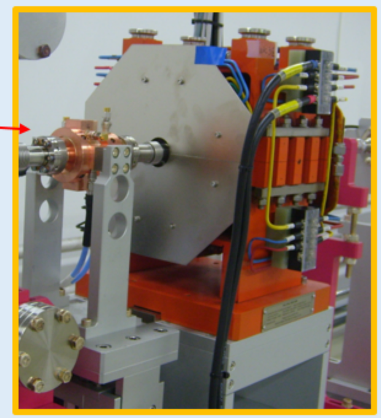
Quadrupole Magnet

S-BPM

electron bunch position

Undulator

C-BPM



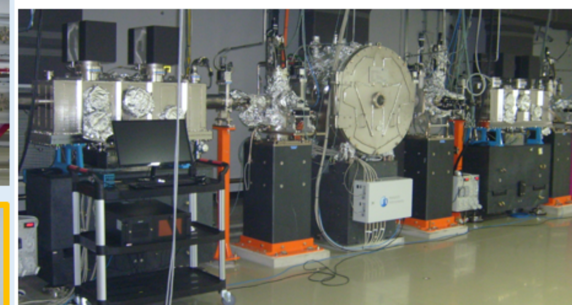
Quadrupole Magnet

C-BPM

electron bunch position

Beamline

Mirror 1 DCM Mirror 2



Mirror & DCM Q-BPM

photon beam position

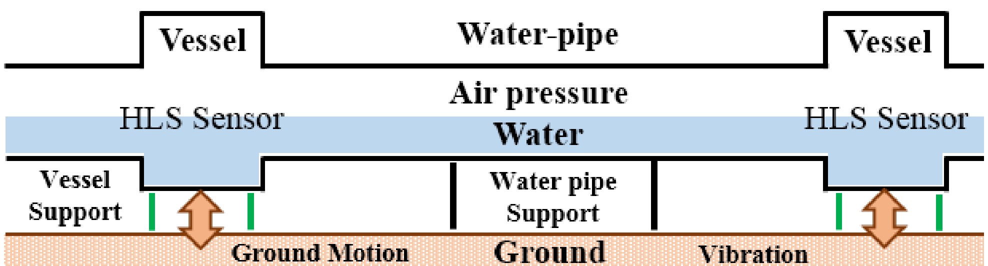
* Beam Base Alignment : weekly & over 50μm

HLS

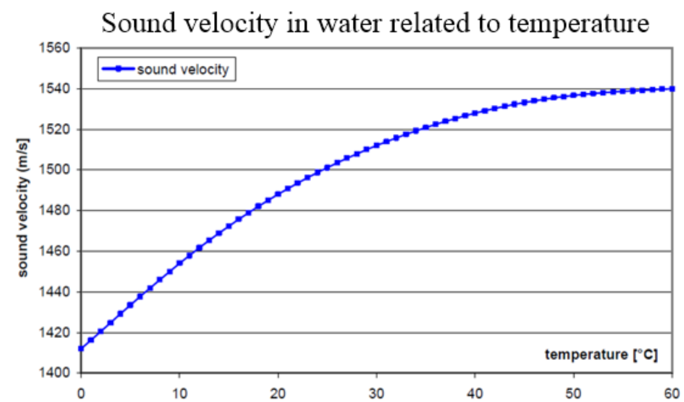
Environment effect to the Water :
① Temperature
② Gravitation force of Earth, Moon and the Sola system
③ Air pressure
④ Vibration (Ground, Air conditioner, Sound)
⑤ Ground Motion

Hydrokinetic and Hydrostatic

Physical & Chemical effect on the water in the water pipe :
① Water droplets form on the pipe surface
② Air bubbling in the water ③ Humidity (Evaporation)
④ Tide ⑤ Pressure ⑥ Ripples
⑦ Thermodynamics (Volume changes of water and pipe)

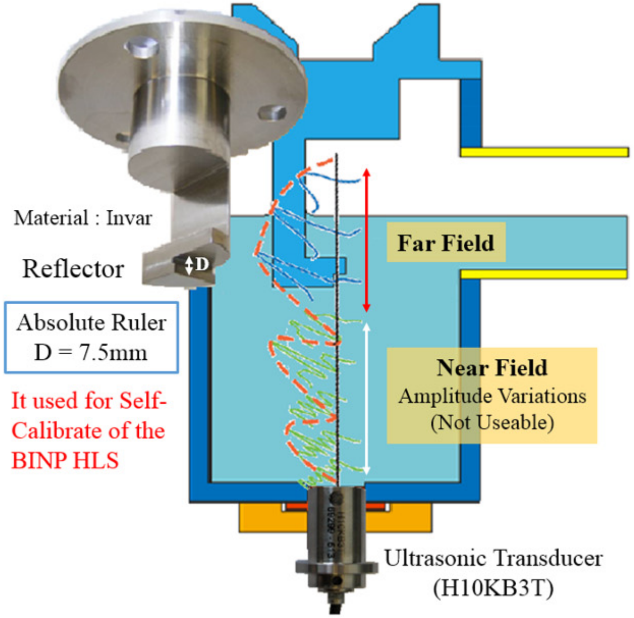


The surrounding environment influencing HLS.

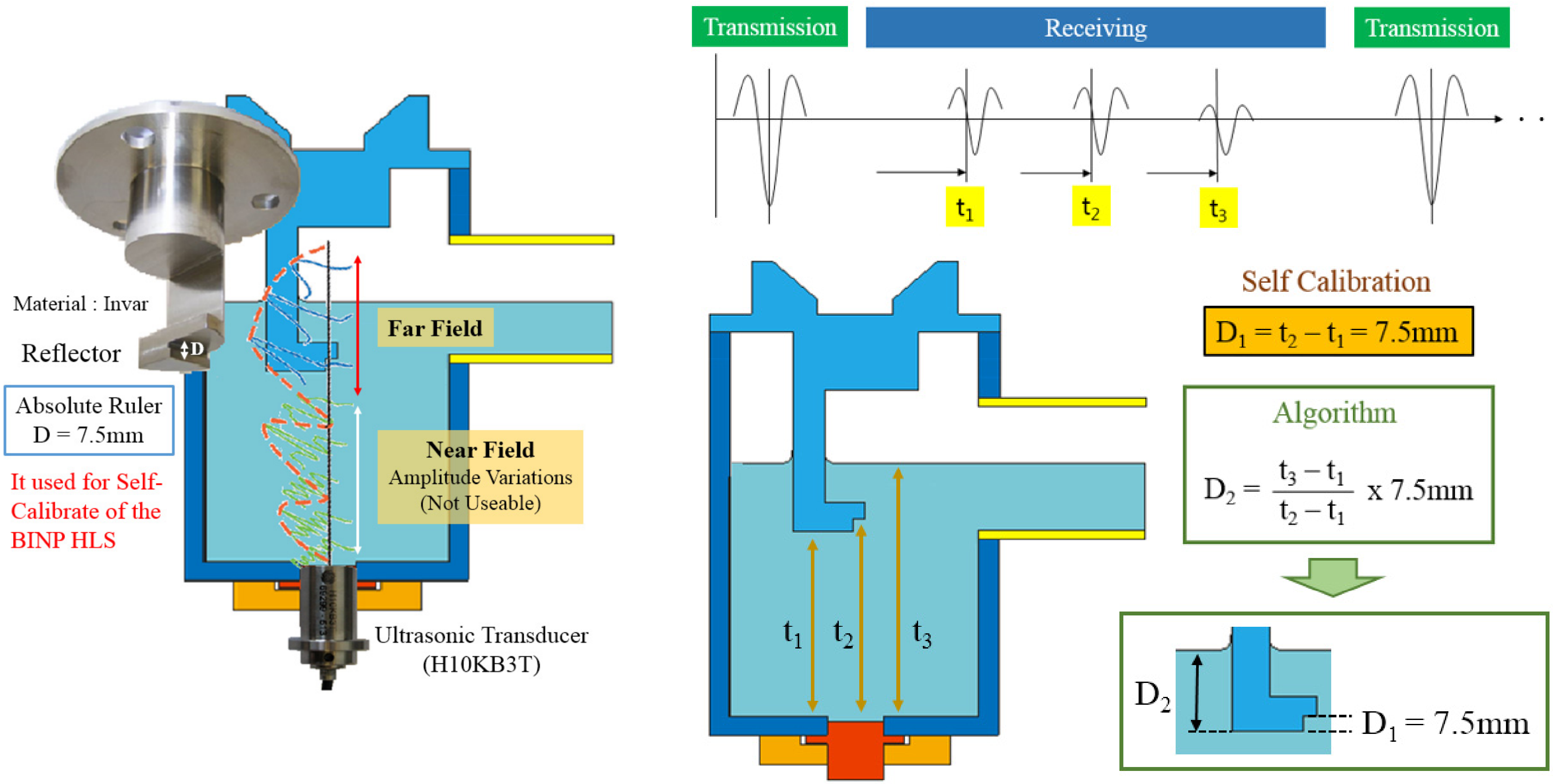


HLS : Self-calibration function

Deutsches Elektronen Synchrotron (DESY) conducted In-situ experiments to develop the Ultrasound sensor for HLS in 2001 and the basic design concept of Ultrasound sensor for HLS was built based on the result of the experiments [1]. The structure of Ultrasonic pulse hydrostatic level sensor developed by Budker Institute of Nuclear Physics (BINP) in Russia [2, 3].



[1] M. Schlösser et al., "High Precision Survey and Alignment of Large Linear Colliders – Vertical Alignment", in Proc. of IWAA 2002. SPring-8, Japan (2002).
[2] A.G. Chupyra et al., "The Ultrasonic Level Sensors for Precise Alignment of Particle Accelerators and Storage Rings", in Proc. of IWAA 2006. SLAC, California, USA (2006).
[3] A.G. Chupyra et al., "BINP Capacitive and Ultrasonic Hydrostatic Level Sensors", in Proc. of IWAA 2008. KEK, Tsukuba, Japan (2008).

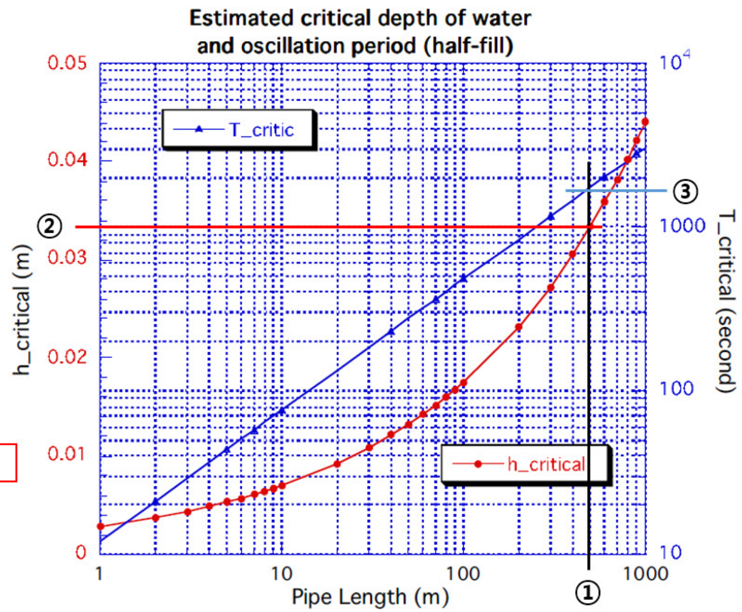


Material : Invar
Reflector
D
Absolute Ruler
D = 7.5mm
It used for Self-Calibrate of the BINP HLS
Far Field
Near Field
Amplitude Variations
(Not Useable)
Ultrasonic Transducer
(H10KB3T)
Transmission
Receiving
Transmission
t_1
t_2
t_3
Self Calibration
$D_1 = t_2 - t_1 = 7.5mm$
Algorithm
$D_2 = \frac{t_3 - t_1}{t_2 - t_1}$ x 7.5mm
t_1 t_2 t_3
D_2
$D_1 = 7.5mm$

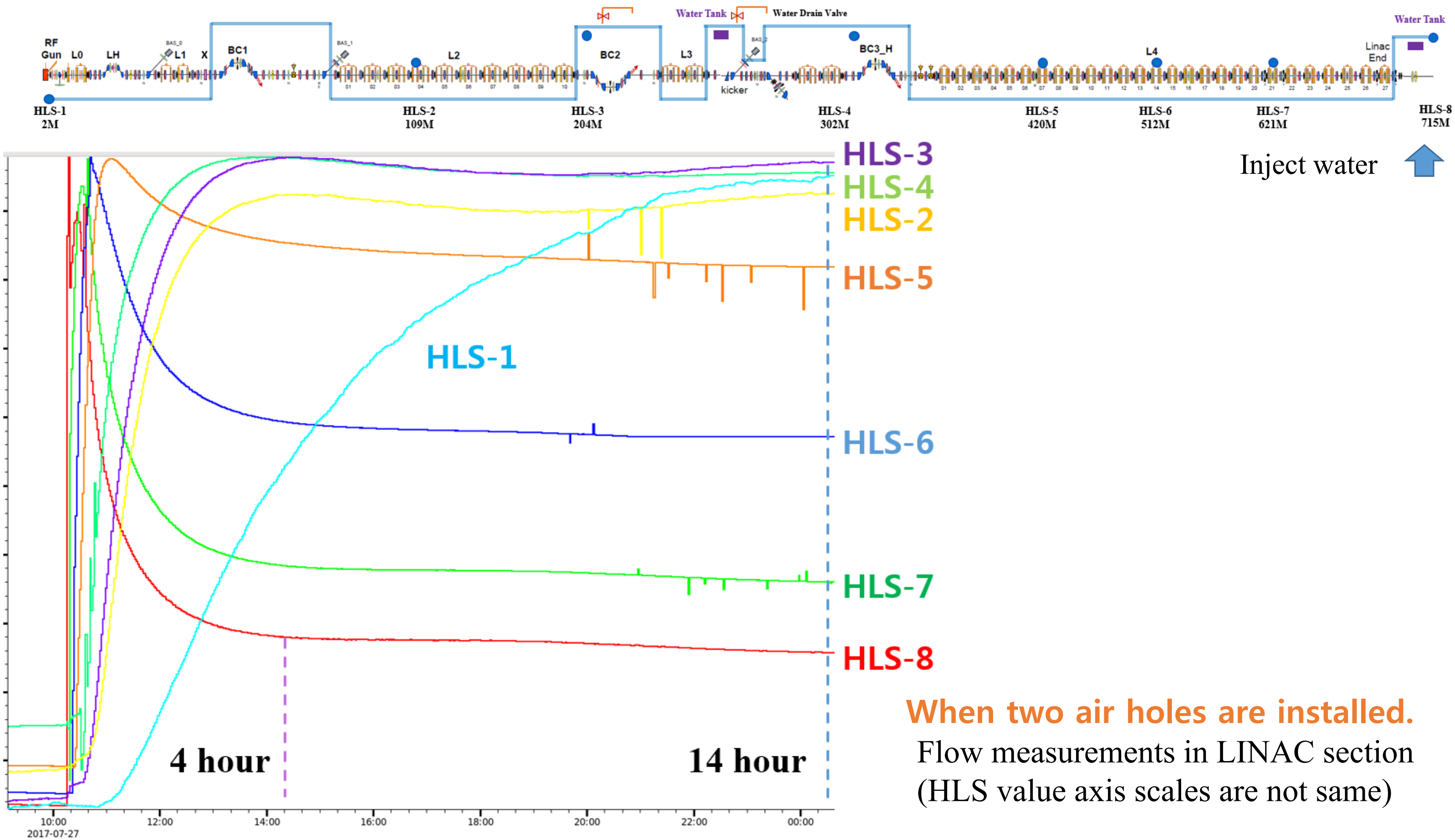
Waterpipe & Air Hole

The time required for the water to maintain balance within the waterpipe is determined by the length (L) and diameter (Ø) of the pipe. The pipe diameter was calculated so that the pipe could be installed in a straight line and so that the time required to balance the water would take about an hour [1].

Distance (m)	Depth of water (m)	Period (sec)
1	0.0028	12
5	0.0053	44
10	0.0070	76
50	0.0133	277
100	0.0175	484
① 500	② 0.0334	③ 1752
1000	0.0440	3050



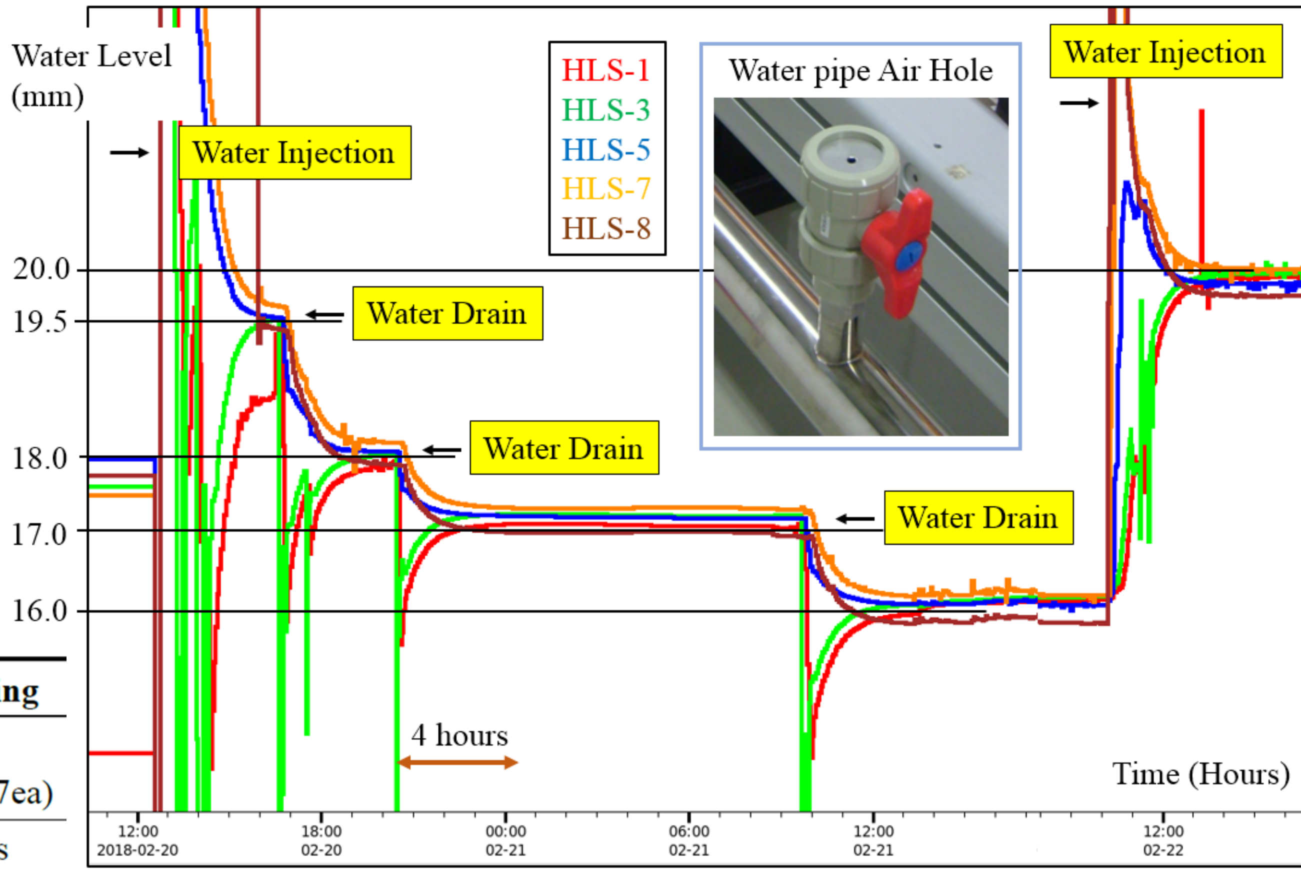
[1] C. Zhang et al., "Primary Hydrokinetics Study and Exper-iment on the Hydrostatic Leveling System", in Proc. of IWAA 2002. Spring-8, Japan (2002).



When two air holes are installed.

Flow measurements in LINAC section

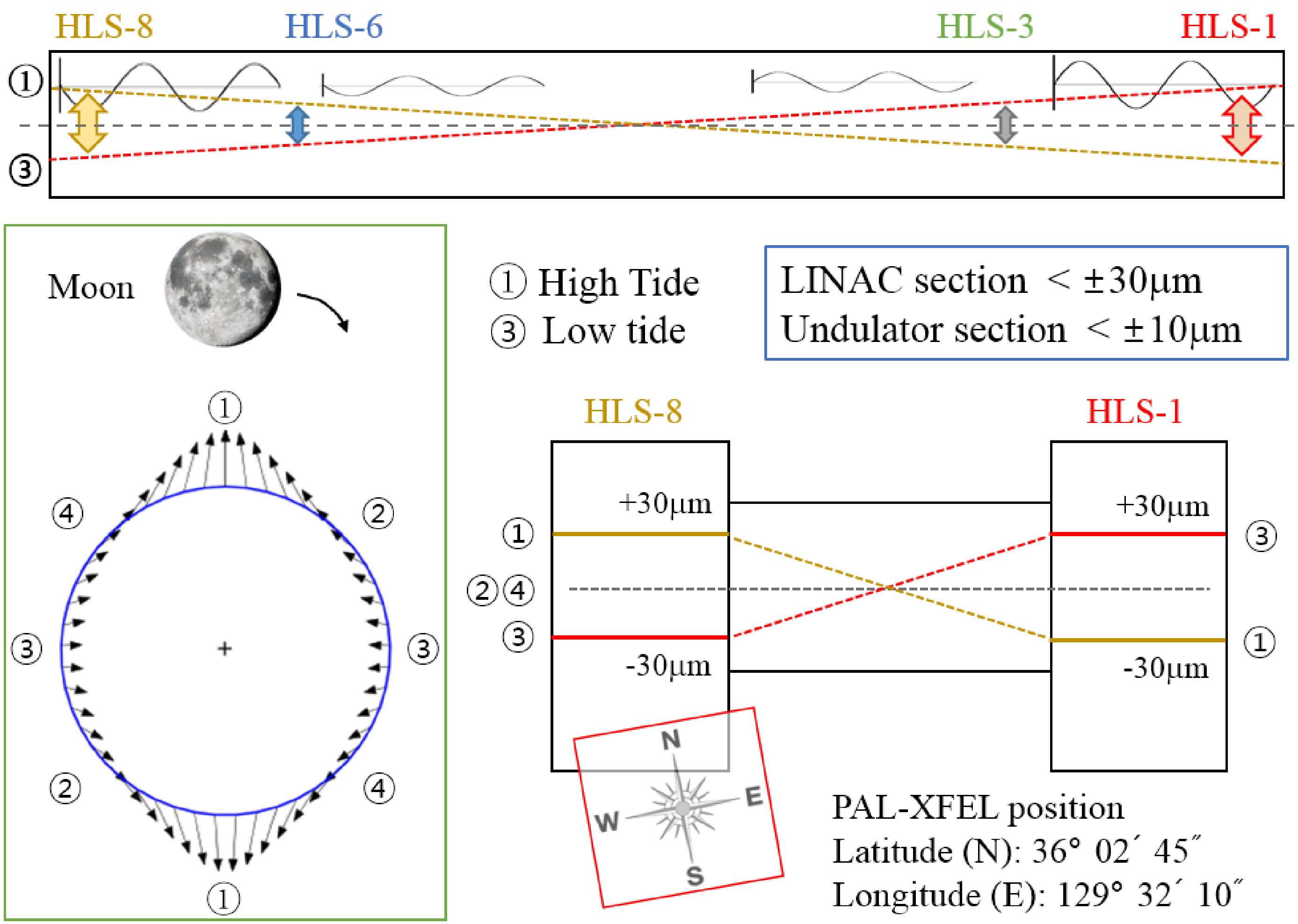
(HLS value axis scales are not same)



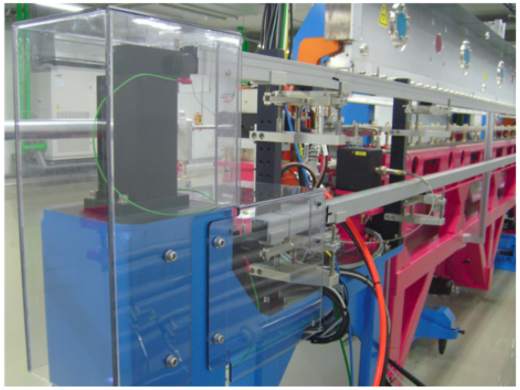
Section	Before adding	After adding
LINAC	14 hours (air hole 2ea)	4 hours (air hole 7ea)
Undulator	2.5 hours (air hole 2ea)	1.5 hours (air hole 4ea)

Hyojin Choi et al., “HLS System to Measure the Location Changes in Real Time of PAL-XFEL Devices”, in Proc. of IPAC2018, Vancouver, Canada, paper WEPAL070 (2018).

Change in the height of water due to tidal-force.

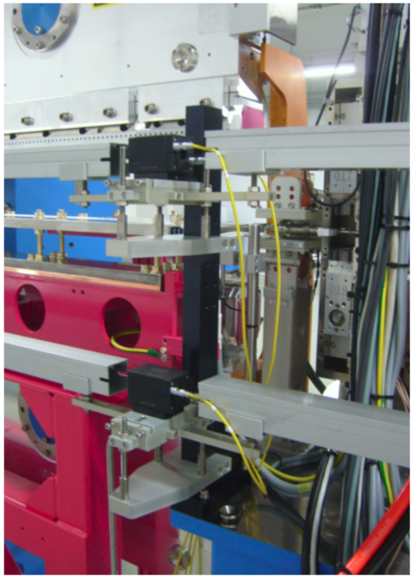


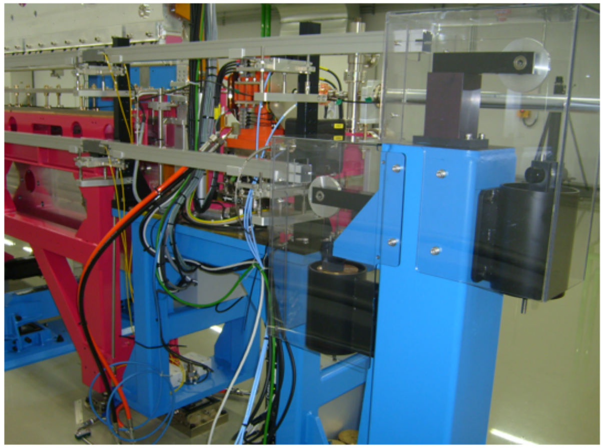
HLS



Wire Fixed Point
- Protect plastic cover

WPS Support & Fixed Bracket
- Wire protect Duct

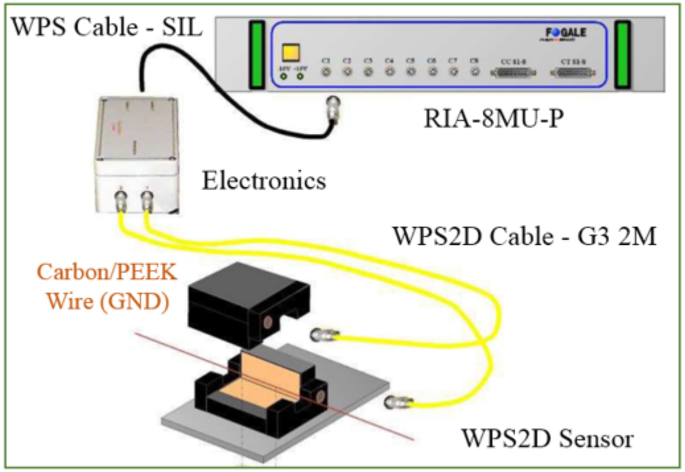




Friction less Pulley
- Counter weight (12~15kg)
- Protect plastic cover

History of WPS to have used on the Accelerator

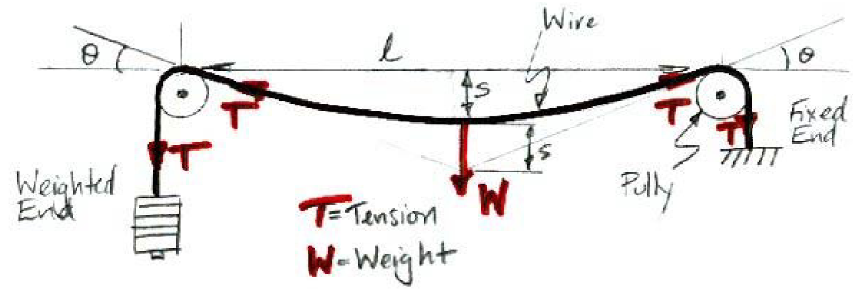
In 1990, the concept of a wire measurement system was first introduced to observe the changes in the ground of a 10-km-long linear collider [1]. The method for transmitting the RF signal to the wire and comparing the strength of the RF signals at the Pickup which is the same as the beam position monitor (BPM) was also examined in 1993. In this case, impedance around a wire should be kept constant at 50ohm to transmit the RF signal over a distance over 100m [2]. In 1995, the European Synchrotron Radiation Facility (ESRF) succeeded in researching and developing a non-contact mono axe (1D) WPS sensor using carbon wire [3]. After that, FOGALE Nanotech developed and commercialized the two dimension WPS2D sensor.

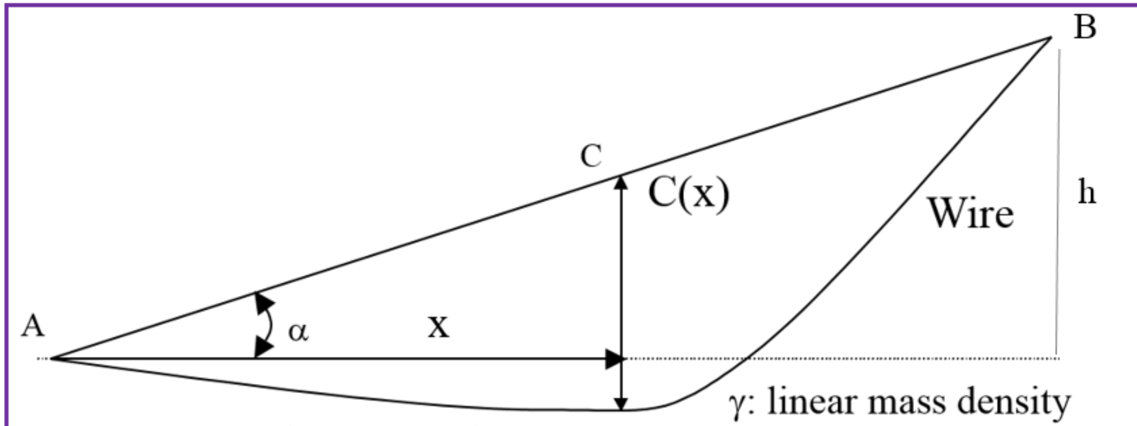


[3] Willfried Schwarz, “Wire measurements for the control of the FFTB-magnets”, Proc. of IWAA1990 (1990)
[4] A. Herty, et al., “Intercomparison Tests with HLS and WPS” Proc. of IWAA2010 (2010)
[5] Daniel Roux, "Status of ESRF Alignment Facilities WPS ready for an automatic 2D smoothing of a storage ring", Proc. of IWAA1995 (1995)

Wire Sag

The calculation formula provided by FOGALE Nanotech





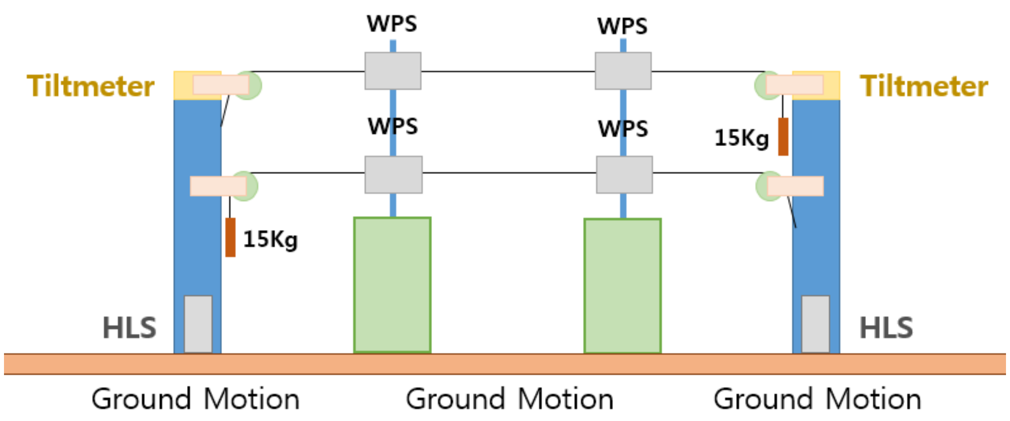
$$C(x) = \frac{\gamma g L}{2T}\left(1 + \left(\frac{h}{L}\right)^2\right)\left(x - \frac{x^2}{L}\right)$$

$$C_{carbon}(x) = 0.03 \text{ x } L^2(m) / T(kg)$$

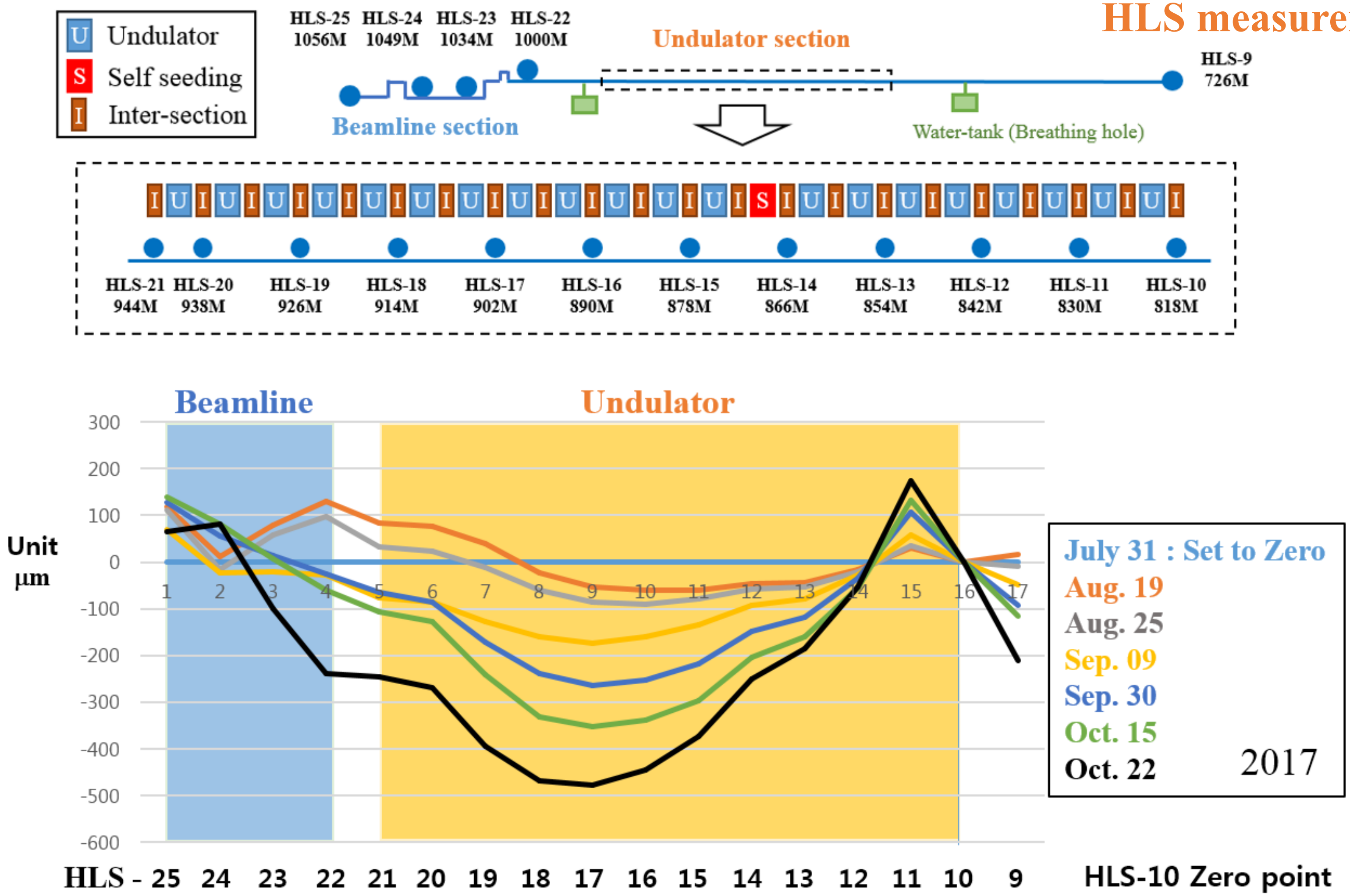
[C unit is mm]

γ: linear mass density
g: gravity
L: horizontal distance between A and B
T: tension
h: vertical distance between A and B

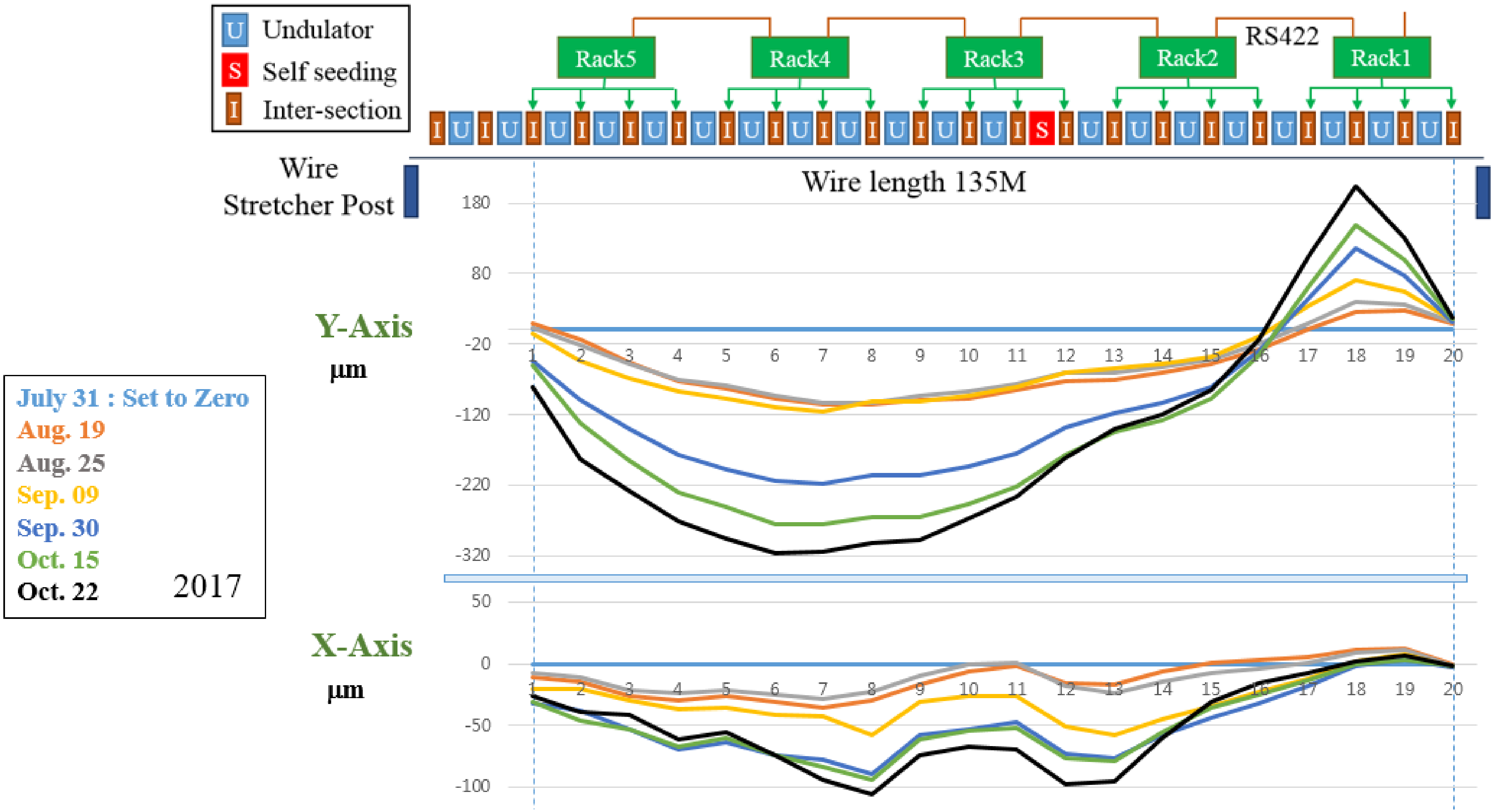
Complementary Relationship of HLS and WPS

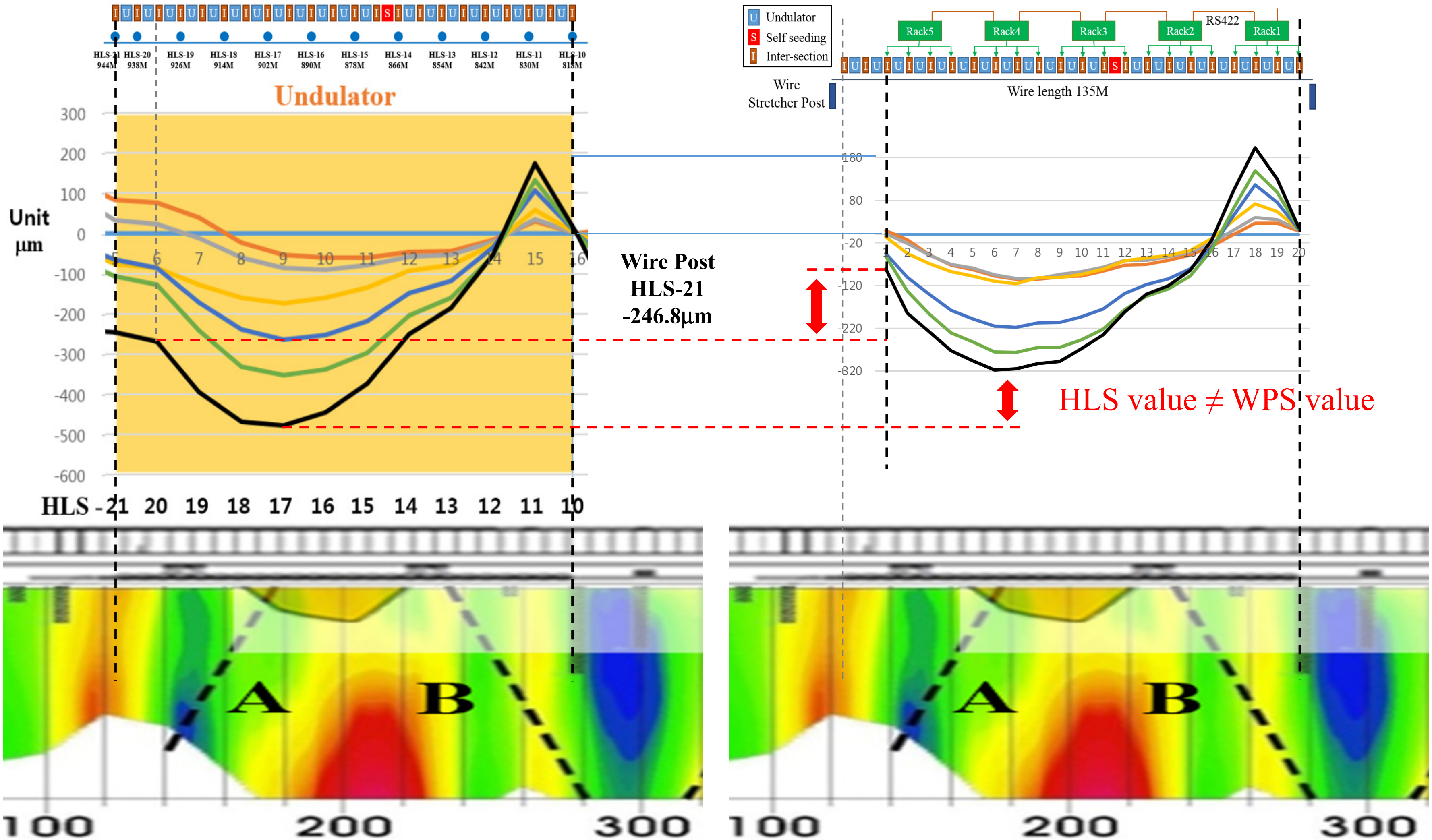


HLS measurements



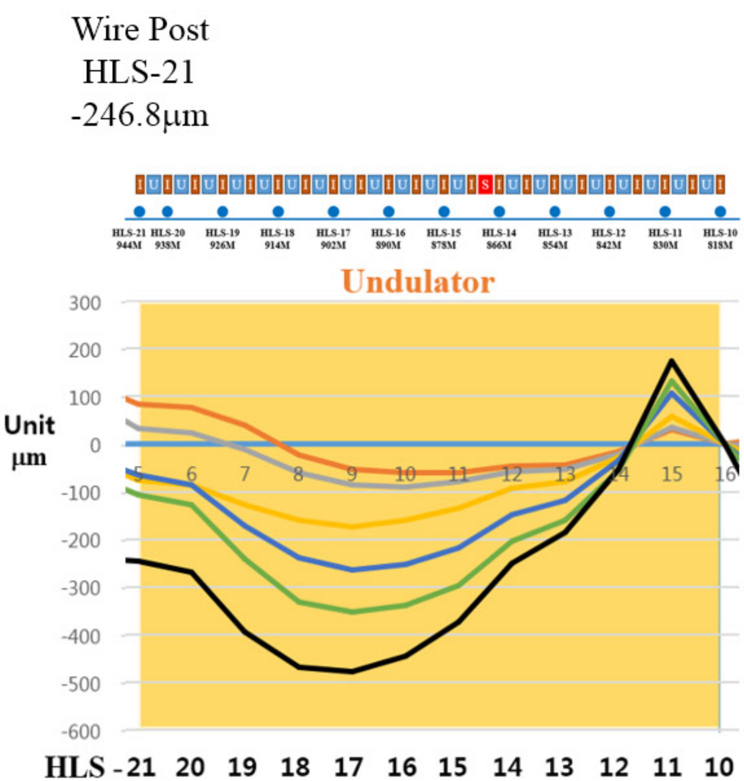
WPS measurements





Undulator
Unit
µm
Wire Post
HLS-21
-246.8µm
HLS - 21 20 19 18 17 16 15 14 13 12 11 10
Undulator
Self seeding
Inter-section
Rack5
Rack4
Rack3
Rack2
Rack1
RS422
Wire
Stretcher Post
Wire length 135M
HLS value ≠ WPS value
A
B
100
200
300

WPS measurement value correction method using HLS.



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