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# CURRENT STATUS OF PAL-XFEL PROJECT

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*Abstract*

The PAL-XFEL, a 0.1-nm hard X-ray FEL facility consisting of a 10-GeV S-band linac, is being constructed in Pohang, South Korea. The installation of linac, undulator, and beam line will be completed by 2015. Its building construction is at its peak moment to be completed by December 2014. The major procurement contract was made in 2013 for the critical components of S-band linac modules and hard X-ray undulators. The commissioning will start in January 2016. We hope the first lasing will be achieved in early 2016.

## CONSTRUCTION STATUS AND SCHEDULE

The PAL-XFEL project started in April 2011 is expected to be completed by 2015. It will include a 10-GeV linac consisting of a photocathode RF gun, 51 klystrons and modulators, 174 accelerating structures, three bunch compressors, one X-band system for RF linearization, and various diagnostic devices. Beyond the 10-GeV linac, a 240-m long undulator hall follows, where three undulator chains will be installed. However, the current budget will cover only one undulator chain. An experimental area 60-meters long and 16-meters wide is located at the end of the facility. The total length of the building is 1,110 meters[1].

Building construction started in September 2012. Since then, 1.2 million cubic meters of soil have been removed, and the concrete shielding of the machine tunnel is completed. It is expected that the building will be ready for use by November 2014. Fig. 1 shows the current status of building construction at the PAL site. Installation of the linac, undulator system, and beamlines will start when the beneficial occupancy of the building is available in fall 2014, and will be completed by the end of 2015.

Figure 1: Construction site of PAL-XFEL.

Figure 2 shows the undulator lines for Phase-1 of PAL-XFEL. Two undulator lines, a hard X-ray FEL line (HX1) and a soft X-ray FEL line (SX1), will be completed by 2015. HX1 will cover the wavelength of λ=0.06 - 0.6 nm, and use linear polarization, variable gap, out-vacuum undulators. The operation mode is SASE for Phase-1, self-seeded for Phase-2. SX1 will cover the wavelength of λ = 1.0 - 4.5 nm. Polarization control is linear for Phase-1, and variable for Phase-2 using two sets of EPU. An enough space for undulators is reserved for future upgrade to house a total of 29 undulators (180 m) for HX1 (18 undulators for Phase-1) and a total of 16 undulators (96 m) for SX1 (8 undulators, 6 PU + 2 EPU).

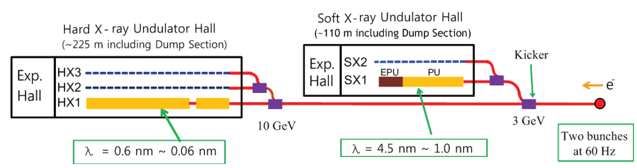


Figure 2: Undulator lines for phase-1 of PAL-XFEL.

Linac RF conditioning and Injector commissioning are scheduled in October to December 2015. The first XFEL commissioning is scheduled in early 2016 aiming for 0.3-nm radiation with 6-GeV beam at 10 Hz for HX1. The 2-nd FEL commissioning is scheduled in September to December 2016 for 0.1 nm HX and 3 nm SX at 10Hz.

## ACCELERATOR STATUS

### *Injector*

The injector test facility (ITF) has been operational since 2012 for the low emittance injector R&D. ITF has the same configuration as the injector of the PAL-XFEL which consists of a photo-cathode RF-gun, two S-band accelerating structures, and a laser heater. The PAL-XFEL baseline gun is a dual-coupler gun with additional two-holes to reduce quadrupole field. The measured projected emittance of the baseline gun is 0.43 µm at 0.2 nC. A laser heater system consisting of a short undulator and four dipoles is being prepared for the beam test in late 2014.

### *Linac*

The major procurement contract was made in 2013 for the critical components of S-band main linac module: SLED, waveguide components, S-band accelerating structures, and klystron modulators. We collaborated with local companies for developing those components in a way of design and test by PAL and fabrication by the company. The collaboration actually started one year before the PAL-XFEL project, and the performance of the prototype was confirmed for the specifications of the PAL-XFEL before the contract. The procurement contract for 43 sets of SLED and a total of 2246 waveguide components (465 directional couplers, 468 E-bends, 138



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3dB power dividers, etc.) was made with Vitzro-Tech in July 2013.

A total of 120 S-band accelerating structures were contracted with MHI, Japan, in year 2011, 2012, 2013, and the remaining 54 units of S-band accelerating structures went to Vitzro-Tech in March 2014. It took about three years for Vitzro-Tech to be able to make an S-band structure withstanding the accelerating gradient of 27 MV/m at 60 Hz and generating the same level of dark current as the MHI structure (see Fig. 3). The Vitzro-Tech accelerating structure is a quasi-symmetric feed coupler with racetrack geometry type having smaller quadrupole kick than the quasi-symmetric feed coupler with round geometry type of MHI structure. Emittance growth due to quadrupole kick is not negligible at low beam energy. Dual feed with racetrack structure is selected for three modules at Injector. Three 2.5-m long S-band deflectors also goes to Vitzro-Tech.

Figure 3: Vitzro-Tech accelerating structure.

To achieve the beam energy stability of below 0.02% and the arrival time jitter of 20fs, the linac RF parameter should be as stable as RF phase of 0.03 degrees and amplitude of 0.02% for S-band RF and 0.1 degree / 0.04% for X-band RF. The pulse-to-pulse klystron RF stability is determined by the klystron beam voltage driven by a modulator. Therefore, the klystron modulator beam voltage should be as stable as 50 ppm for 0.03 degree S-band RF and 0.1 degree X-band RF.

A total of 51 klystron modulators were contracted with POSCO-ICT and Dawon-Sys in June 2013. Both companies showed its prototype satisfies the requirement of the beam voltage stability of 50 ppm in rms. The achieved stability is below 30 ppm at the klystron beam voltage, while it is below 10 ppm at the PFN voltage. The modulator uses an inverter type high voltage power supply and is capable of operating at 200 MW peak power and 60 Hz for the 80-MW, 4-μs S-band klystron. Figure 4 shows the first modulator being tested at the factory. The PFN is designed to be easily changed to have a shorter RF pulse length of 1.5 μs or shorter suitable for de-tuned operation of SLED, which allows us to increase the modulator pulse repetition rate from 60 to 120 Hz. The contract includes one modulator for SLAC X-band klystron for an X-band linearizer.


Figure 4: The first klystron modulator at the factory.

The procurement contract for 55 units of LLRF systems was made with Mobiis in March 2014. The required specification of the LLRF is the RF phase and amplitude of 0.03 degree and 0.02% in rms, respectively, at the output of 80-MW klystron amplifier. Even though the proto-type performance was 0.038 degree in the RF phase and 0.012% in the RF voltage, we decided to make a contract because we expect the company can achieve the RF phase requirement of better than 0.03 degree.

A 1-kW level solid-state amplifier was also developed with two local companies, which will be contracted with one of them in July 2014 for 55 units. A total of 260 high power SiC loads will be contracted right after its performance is verified.

A 50-MW X-band klystron (XL4 type klystron) and X-band waveguide components will be provided from SLAC by April 2015. A linearizer cavity, H60GV3 X-band Structure, will be delivered to Pohang by September 2014. It is 0.6 m long and placed before the first bunch compressor BC1. The H60 structure has a smaller wake loss even though it requires more RF power than T53.

### *Undulator*

The HX undulator minimum gap was changed from 7.2 mm to 8.3 mm in order to increase the undulator chamber aperture from 5.2 mm to 6.7 mm, which makes sure that wake field effects and exposure of magnets to irradiation are reduced. Therefore, the undulator period is changed from 24.4 mm to 26.0 mm.

A prototype of 5-m long out-vacuum undulator adopting the EU-FEL design was measured at the undulator field measurement lab (see Fig. 5). The undulator measurement room is under a highly stable temperature control of ±0.1°C. Hall probe scan, flip coils and stretched wire systems are equipped for undulator measurement.

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Figure 5: A proto-type undulator at the undulator measurement lab.

The requirement of undulator field accuracy is better than 2 x $10^{-4}$ and the undulator gap setting accuracy should be below 1 um. Figure 6 shows the measurement of gap reproducibility errors. The peak fields from 5 measurements are overlapped. Between each measurement, gap is opened to 100mm and closed to measurement gap. A 1.5 Gauss difference translates to 1.0 µm gap error. After a successful test of the prototype, we made a contract for a total of 18 HX undulators with SFA in September 2013.

Undulator chamber thickness is changed from 0.5 mm to 0.4 mm. To ensure the strength of the chamber, the chamber shape is changed from racetrack to ellipse. The e-beam chamber cross section is 6.7 x 13.4 mm.

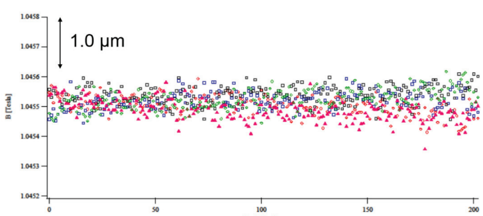


Figure 6: Measurement of gap reproducibility errors.

The magnet is classified as 7 different families of dipole magnets and 11 families of quadrupole magnets. Its design and proto-type is almost finished (see Fig. 7). D3 and D7 for the dump dipole magnets have C-type core shape, and the rest of all have H-type which has good symmetry.

## *Control System*

An event timing system that reconfigured as LCLS event-timing software and delivered from SLAC in February 2014 is being successfully commissioned at the ITF. Beam synchronous acquisition with this event timing system will be tested at ITF for BPM, charge monitor, LLRF, wire scanner, and beam loss monitor.

A prototype of stripline BPM control system delivered from SLAC will be tested at ITF in late June 2014. It is a mTCA based system developed by SLAC. A three-BPM measurement system installed at ITF will be used for the measurement of BPM resolution.

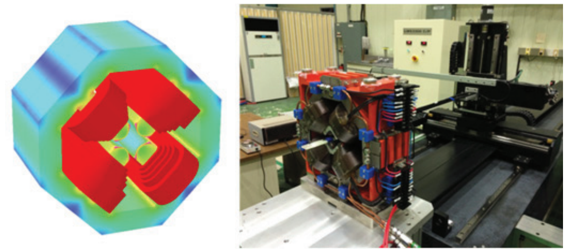

Figure 7: FEM model and field measurement of quadrupole magnet Q2.

Collaboration R&D with SLAC for X-band cavity BPM is under way for the resolution of < 500 nm @ 200 pC. SLAC is in charge of the BPM electronics and PAL takes care of the cavity design and fabrication. The cavity is a coaxial pick-up type much simpler than the waveguide pick-up type in LCLS. The first beam test for a proto-type was done at SLAC in August 2013 showing that the horizontal resolution is fine, 0.4 µm, while the vertical resolution is poor, 10 µm. It is due to over coupling of the vertical pick-up. The second cavity BPM with smaller coupling coefficient recently fabricated at PAL was sent to SLAC to be tested again in July 2014 (see Fig. 8).

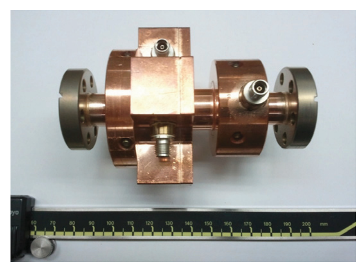

Figure 8: Second cavity BPM.

## *Dechirper*

In August 2013, LBNL and SLAC experts were onsite at ITF to test a dechirper, an interesting instrument consisting of a vacuum chamber of two corrugated, metallic plates with an adjustable gap. One-meter long proto-type of dechirper was tested successfully to accurately measure the longitudinal, dipole, and quadrupole wakes [2]. This experiment gives us confidence in the practical use of a dechirper in place of more expensive options.

## REFERENCES

[1] Kang, H.S. et al. Current Status of PAL-XFEL Project. *Proc. IPAC Conf. 2013* paper WEODB103 (2013).
[2] Paul Emma et. al., PRL 112, 034801 (2014).

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