CURRENT STATUS OF PAL-XFEL PROJECT

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Abstract

The PAL-XFEL is a 0.1-nm hard X-ray FEL construction project which started from 2011 with a total budget of 400 M$. The PAL-XFEL is designed to have three hard X-ray undulator lines at the end of 10-GeV linac and a dog-leg branch line at 3 GeV point for two soft X-ray undulator lines. The three-bunch compressor lattice (3-BC) is chosen to have large flexibility of operation, making it possible to operate soft X-ray FEL undulator line simultaneously and independently from hard X-ray FEL line. Self seeding to achieve the FEL radiation bandwidth of below 5×10^{-5} is baseline for the hard X-ray FEL line. Polarization control will be available by using the PU + EPU layout for the soft X-ray FEL line. The overview of the project with the current status is presented.

OUTLINE

The PAL-XFEL is a 0.1-nm hard X-ray FEL project aiming at providing photon flux higher than 1 x 10^{12} photons/pulse at 0.1 nm using a 0.2 nC / 10 GeV electron linac (see Fig. 1). The photon flux of 1 x 10^{12} at 0.1 nm corresponds to the FEL power of 30 GW with the pulse length of 60 fs in FWHM. Three-bunch compressor lattice (3-BC lattice) is chosen so as to make more electrons in a bunch meet the requirements of emittance and correlated energy spread for FEL. The 3-BC lattice can minimize the emittance growth due to CSR as well [1].

Figure 1: Artistic view of PAL-XFEL.

Figure 2 shows the schematic layout of the PAL-XFEL. The PAL-XFEL will be a 10 GeV hard X-ray XFEL facility with a switch line at 3 GeV point for soft X-ray FEL. It consists of a 139-MeV injector, four acceleration sections (L1, L2, L3, and L4), three bunch compressors (BC1, BC2, BC3), and a dogleg transport line to undulators. The injector uses an S-band photo-cathode RF-gun capable of slice emittance smaller than 0.3 mm-mrad at 0.2 nC. A laser heater, which placed right after the injector, is to mitigate micro-bunching instability, and an X-band cavity placed after L1 is to linearize the non-linear energy-to-time correlation. The energy chirp required in the bunch compression process is well compensated in the hard x-ray FEL beamline due to the long acceleration section L4, while it is not available in the soft X-ray FEL beamline because there is no wake structure after the last bunch compressor (BC3-S). A de-chirper system located right after BC3-S in the soft X-ray FEL beamline is a corrugated pipe system to actively use resistive longitudinal wake field.

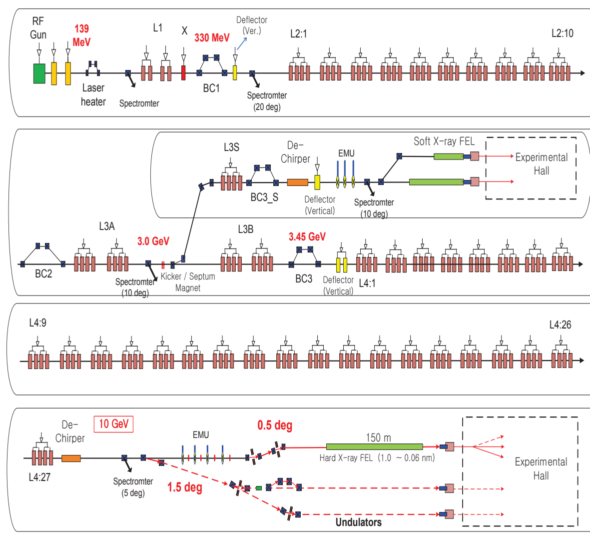

Figure 2: Schematic layout of the 3-BC lattice of PAL-XFEL.

The 3-rd bunch compressor for the hard X-ray FEL beamline is located at 3.45 GeV, while the soft X-ray FEL beamline has its own third bunch compressor (BC3_S). A switch line to soft x-ay FEL beamline consists of a kicker and a Lamberston type septum. A simultaneous operation is feasible for the soft X-ray and hard X-ray FEL beamline with flexibility in control of bunch current and bunch length by changing the bend angle of the 3-rd BC of each FEL beamline.

The target emittance (slice emittance) at the entrance of undulators is 0.4 mm-mrad at 0.2 nC and the acceptable emittance is set at 0.6. The undulator is variable-gap out-vacuum type, 5-m long undulator with the minimum gap of 7.2 mm. It adopts the EU-FEL design concept.

Figure 3 shows the layout of hard X-ray and soft X-ray FEL beamlines. Two FEL beamlines, one soft X-ray (SX1) and one hard X-ray (HX1), which will be prepared in the first phase, are to provide the FEL beam in the range of 0.6 to 0.06 nm and 4.5 to 1 nm, respectively. The shortest wavelength of HX1 beamline is extendable to 0.06 nm by changing the undulator gap.

The photon fluxes of the SX1 FEL radiations are larger than 1.0E^{12} at the pulse length of 90 fs. The SX1 undulator line is nominally to deliver the FEL radiation from 3 nm to 1 nm, while it is able to deliver a 4.5 nm FEL beam by reducing the beam energy from 3.15 to 2.55 GeV. To have a capability of full polarization control in the soft x-ray FEL, APPLE-II type undulators are used.

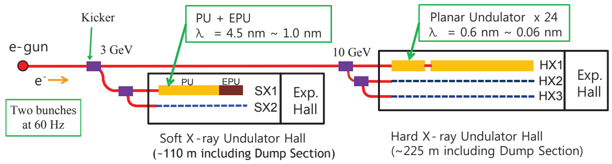

Figure 3: Layout of hard X-ray and Soft X-ray FEL line.

The saturation power of 0.1 nm radiation is calculated to be only 15 GW by the MingXie formula using the electron beam parameters of the PAL-XFEL, which is smaller than the target value of 30 GW. The self-seeding scheme is the baseline for the PAL-XFEL to increase the radiation power over 100 GW as well as better longitudinal coherence by two orders of magnitude than the SASE scheme. This self-seeding scheme requires a very stable electron beam with energy jitter below 0.02% that becomes one of the target parameters of the PAL-XFEL.

PROJECT STATUS

The PAL-XFEL project started in 2001 with a 4-year budget of 400 M$ has made a big progress in ground preparation work being completed in May 2013. The construction of 1,110-m long building will be completed by November 2014. The budget of the years 2011, 2012, 2013 are 20 M$, 45 M$, and 85 M$, respectively. The project period has a good possibility of extending one more year due to the budget. If this happens, the accelerator installation will be finished in 2015 and the commissioning will be followed.

Self-seeding and Polarization Control

Self-seeding simulation is being carried out to see that the peak radiation power reaches over 150 GW and the bandwidth is 3.7x10^{-5}.

We need to generate a circularly polarized X-ray with polarization larger than 95% for the soft X-ray FEL line. Even though the best arrangement is to use all helical undulators (HU), we try the PU + EPU layout to reduce the length of HU.

Linac

Tolerance study for RF phases and amplitudes of linac RF system is completed satisfying the stability requirement of electron beam at the entrance of undulator; bunch current: $|\Delta I/I_0| < 10\%$, energy: $|\Delta E/E_0| < 0.02\%$, arrival time: $|\Delta t| < 20\ fs$, emittance: $|\Delta \varepsilon/\varepsilon_{n0}| < 5\%$. The most stringent requirement of RF phase and amplitude is 0.03 deg and 0.01%, respectively, for L1.

Low-level RF feedback controller can control RF phase and amplitude at low speed (a few Hz), therefore cannot control the pulse-to-pulse klystron RF jitter because of the pulse nature of the klystron modulator. So, the klystron modulator itself should be stable enough to satisfy the requirement.

The accelerator test facility (ATF) has completed its installation in October 2012 to develop an ultra stable klystron modulator (see Fig. 4). A prototype of klystron modulator developed with two local companies shows the voltage stability of below 30 ppm, which is smaller than the requirement of 50 ppm that comes from the beam energy stability requirement for self-seeding. The modulator uses inverter type high voltage power supply and is capable of operating at 200 MW peak power and 60 Hz for the 80-MW S-band klystron.

The design of RF system for X-band linearizer is finished. We are in discussion with SLAC for delivery of a 50-MW X-band klystron and X-band waveguide components. Collaboration R&D for X-band cavity BPM with SLAC is on-going and the beam test at SLAC for a proto-type of PAL design is scheduled in August 2013.

Figure 4: A proto-type of klystron modulator.

Injector Test Facility

The injector test facility (ITF) has completed its installation in October 2012, and is under the beam commissioning (see Fig. 5). 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.

Two candidate designs are being prepared for the PAL-XFEL gun. One is the PAL-XFEL baseline gun which is dual-coupler gun with additional two-holes to reduce quadrupole field (see Fig. 6). The other is an alternative gun design which adopts a fully-symmetric coaxial coupler and cathode plug.

The measured beam energy is 139 MeV and the projected emittance of the baseline gun is measured at 0.2 nC to be 1 μm for horizontal direction, 0.74 μm for vertical direction, respectively.

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Laser cleaning is firstly done to improve QE from 4.0 x10^{-5} to 1.3x10^{-4}. We compared UV cleaning (1ps, 44 μJ) with IR cleaning (~100 ps, 400 μJ). IR cleaning shows the similar QE improvement while shows no emittance degradation unlikely to UV cleaning.

A deflector S-band cavity will be installed at ITF in May to measure the slice emittance and a laser heater undulator will be installed in September 2013.

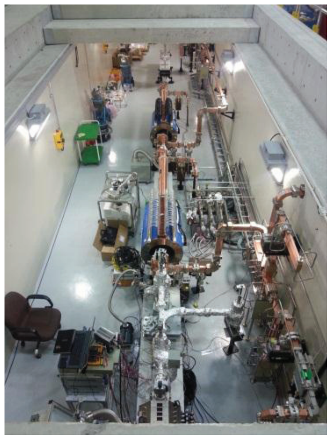

Figure 5: Injector test facility.

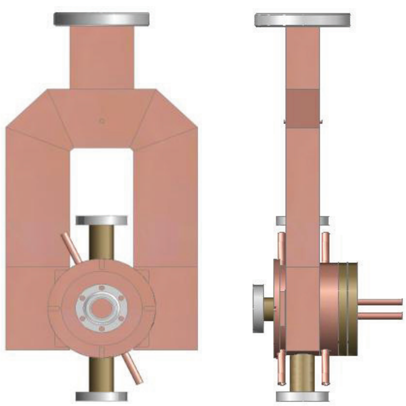

Figure 6: Photocathode RF-gun.

Dechirper

Energy chirp required for bunch compression is different for different bunch length and charge. A de-chirper with cylindrical geometry of fixed diameter lacks controllability. So, adjustable gap type using two parallel plates with corrugations is chosen as a practical design to have better controllability. However, it introduces dipole and quadrupole wakes.

Collaborative R&D with SLAC and LBNL for dechirper system is underway to evaluate these wake effects. One-meter long proto-type of dechirper is being prepared and the beam test will be done at Injector Test Facility in July 2013. Longitudinal, dipole, and quadrupole wakes will be examined at the beam test.

Undulator

A prototype of 5-m long out-vacuum undulator adopting the EU-FEL design was fabricated by a local company (see Fig. 7). It is now being measured at the undulator field measurement lab (13-m wide and 64-m long) where there are two measurement rooms with a 0.1°C temperature control capability to measure a total of 42 undulators for one and half years. A proto-type of phaseshifter is also fabricated and the magnetic field is measured to evaluate the design.

Figure 7: A proto-type of undulator.

Undulator Chamber

The undulator chamber is designed to have an e-beam chamber with cross-section of 5.2 x 11 mm and thickness of 0.5 mm (see Fig. 8). It also has a hole for correction coil to make earth magnetic field below 0.1 Gauss. Another circular hole is for the water cooling line to cool down heat from the correction coil. Fabrication of the 2nd prototype undulator chamber is finished and it satisfies the vacuum requirements (< 5E^{-7} Torr @ 100 h) and the surface requirements of roughness < 200 nm and oxide layer thickness < 5 nm. Design of the undulator intersection is done. And wake effect of intersection components will be estimated.

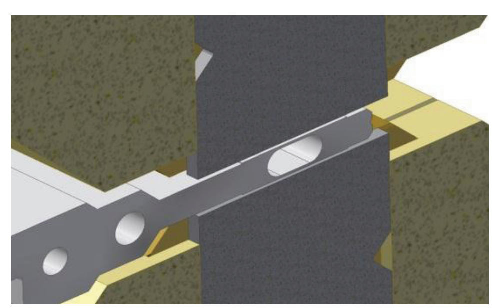

Figure 8: Cross-section view of undulator chamber.

REFERENCES

[1] Kang, H.S. et al. START TO END SIMULATION OF THREE BUNCH COMPRESSOR LATTICE FOR PAL XFEL. *Proc. IPAC Conf. 2012* paper TUPP062 (2012).