STATUS OF THE PAL-XFEL PROJECT*

In Soo Ko#,
Pohang Accelerator Laboratory, POSTECH, Pohang, Kyungbuk, 790-784 Korea

Abstract

PAL-XFEL, the new X-ray FEL machine that is going to be built at Pohang Accelerator Laboratory, is under intensive design study and machine R&D. The electron beam energy will be 3.7 GeV and the fundamental wavelength will be 0.3 nm and its third harmonic 0.1 nm will also be used. The project will proceed in two stages: In the first stage, a VUV SASE machine with 320 MeV will be constructed and tested for the proof-of-principle. The full X-ray machine will be constructed in the next stage.

INTRODUCTION

PAL-XFEL is the name of new project of Pohang Accelerator Laboratory (PAL) to build a new X-ray FEL machine based on SASE (self amplified spontaneous emission) scheme. This new machine will utilize the existing 2.5 GeV electron linac by increasing its energy to 3.7 GeV and upgrading the performance. The linac is currently used for injection to the 2.5 GeV storage ring of Pohang Light Source (PLS). The new linac energy will be 3.7 GeV. The overview of the PAL-XFEL project was reported previously [1]. For readers unfamiliar with the project, fundamental parameters of PAL-XFEL are listed in Table 1 and the machine layout is displayed in Fig. 1. At the moment, detailed design study and machine R&D are going on. In the figure, K2,...,K12 denote the currently used accelerating columns and X1,...,X9 denote the new accelerating columns that will be added to the existing linac. X3X denotes the X-band high harmonic cavity. We are going to build the new part of PAL-XFEL while still running PLS.

However, there have been a few modifications in the PAL-XFEL project. The first important modification is the target wavelength that will be used mainly. The X-ray community, which is the biggest synchrotron user community in Korea, has demanded that the target wavelength be in 0.1 – 0.15 nm range, which put quite a challenge for the PAL-XFEL design. Since the available linac energy of PAL is limited, we decided to utilize the third harmonic radiation of SASE. It is well known that the high harmonic radiations are also amplified to FEL by the so called nonlinear harmonic generation [2,3]. The existence and usefulness of SASE higher harmonic radiation was verified experimentally in VUV-FEL at DESY [4]. The fundamental wavelength of PAL-XFEL will be 0.3 nm and the third harmonic will be 0.1 nm, both of which will be used. According to calculation based on [5], the third harmonic radiation power is approximately 1% of the fundamental one.

Another important modification is the procedure of PAL-XFEL construction. The PAL-XFEL project will proceed in two stages. In the first stage, only a small 320 MeV SASE machine will be constructed. The purpose of this machine is to test and prove the design strategy of PAL-XFEL. Hence, this test machine (TM) will use the same undulator as PAL-XFEL. Only in the second stage, the full PAL-XFEL will be constructed. Design study of TM is going on.

Machine R&D is also going on with particular emphasis on the photo injector. In this status report, major modifications of the project and R&D status will be presented.

Table 1: Margin Specifications

Parameter	Value	Unit
Electron energy	3.7	GeV
Peak current	3	kA
Normalized slice emittance	1	mm mrad
RMS slice energy spread	0.01	%
Full bunch length	270	fs
Undulator period	1.5	cm
Segment length	4.5	m
Full undulator length	80	m
Peak undulator field	1.19	T
Undulator parameter, K	1.49	
Undulator gap	4	mm
Average β-function	10	m
Radiation wavelength	3	Å
FEL parameter, ρ	5.7×10^{-4}	
Peak brightness	5×10^{31}	*
Peak coherent power	1	GW
Pulse repetition rate (Max)	60	Hz
1D gain length	1.2	m
Saturation length, Lsat	45	m

* photon/(sec $mm^2 mrad^2$ 0.1%BW)

TEST MACHINE

The purpose of TM is to prove, in the low energy, that PAL-XFEL is achievable. It will not be used as a user facility. The reason why we need TM is that PAL-XFEL is challenging. It is challenging to generate 0.3 nm radiation with 3.7 GeV electron beam. That is why PAL-

*Work supported by the Korean Ministry of Science and Technology
#isko@postech.ac.kr

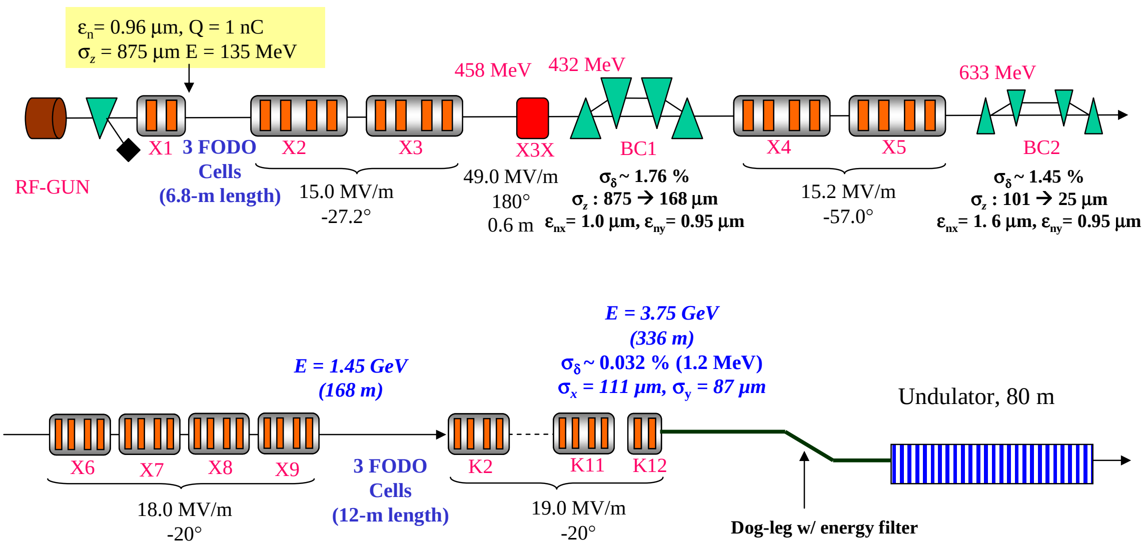

Figure 1: Layout of the PAL-XFEL injector and linac.

XFEL uses in-vacuum undulator. The validity of the PAL-XFEL scheme will be proved by TM. TM will have a low energy of 320 Mev lower than a tenth of PAL-XFEL energy, but the undulator will be the same as in PAL-XFEL except the total length. It will still adopt a pair of bunch compressors, but X-band higher harmonic cavity is not planned to be used at the moment. Beam parameters are chosen to give comparable magnitude of energy spread to the PAL-XFEL case. The optimal average beta function of the undulator lattice is reduced from 10 m of PAL-XFEL to 5 m. A few fundamental parameters of TM are shown in Table 2.

INJECTOR

The photo-cathode RF gun is one of the essential elements for the success of SASE FEL. Our aim is to achieve normalized slice emittance of 1 micron or smaller for 1 nC bunch charge. The design pulse length is 10 ps and the final energy of the injector is 135 MeV. For the purpose of the injector R&D, a gun test stand (GTS) was prepared and a prototype 1.6 cell photocathode RF gun has been installed [6]. GTS also includes a radiation shielding tunnel, a full set of RF system, and a high power Ti:Sapphire laser system with a clean room facility that can control temperature within 0.5 degree. Figure 3 shows the Ti:sapphire laser system [7]. It consists of the oscillator, regenerative amplifier, a third harmonic generator, and a custom designed UV stretcher system. From the oscillator, 800 nm wavelength infrared laser pulses are generated with 105 fs pulse width and 80 MHz repetition rate. These laser pulses come into the regenerative amplifier to be amplified up to 2.5 mJ energy

Table 2: Parameters of the test linac

Parameters	Value	Unit
Electron energy	0.32	GeV
Peak current	0.7	kA
Normalized slice emittance	0.8	mm mrad
RMS slice energy spread	0.01%	
Average beta function	5	m
Radiation wavelength	28	nm
FEL parameter	3.4×10^{-3}	
1-D gain length	0.2	m
Saturation length	6	m

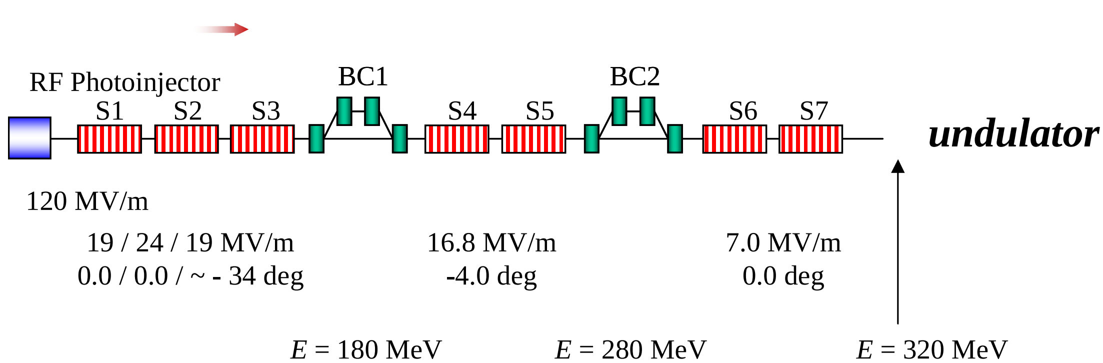

Figure 2: Layout of the test linac.

laser pulses with 1 kHz repetition rate. During the amplification, the chirped pulse amplification method is used to prevent a damage of the gain medium. The 2.5 mJ energy of the IR laser is supposed to give 1 nC charge.

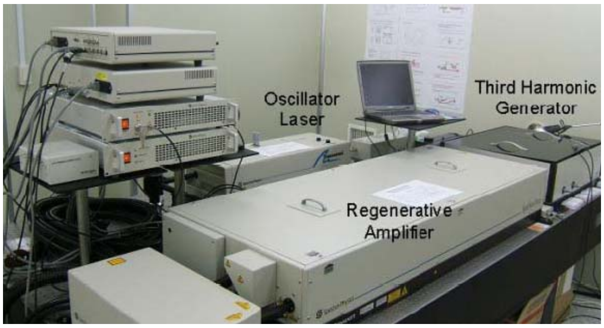

Figure 3: A picture of Ti:sapphire system.

Electron beam is successfully generated from the photocathode RF gun and its charge and size have been measured. We installed an integrated charge transformer and a phosphor screen at 40 and 50 cm distance from the cathode, respectively. The charge coupled device camera is synchronized with 10 Hz repetition rate of RF and the electron beam is focused on the phosphor screen due to a solenoid magnet. Figure 4 shows an image of the electron beam on a phosphor screen. The electron beam energy was 2 MeV, the initial phase was 30 degree, and the beam charge was 320 pC. The laser pulse length at FWHM was 6 ps and the normalized rms emittance was 4 mm mrad.

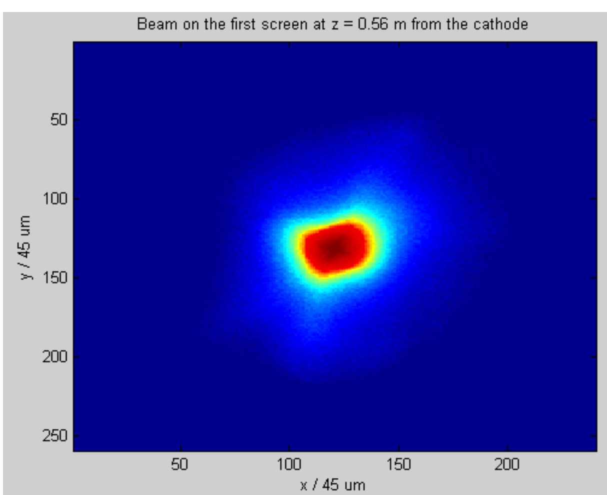

Figure 4: Electron beam image from the GTS gun on a phosphor screen.

It was observed that the beam size changes according to the RF phase and the measured RMS radius was 500 µm at the 50 degree RF phase. Measured beam charges under various RF phases and laser energies are plotted in Fig. 5.

The electron beam was observed from 0 to 120 degree RF phase and the maximum charge was observed at the 70 degree. In addition, the measured electron beam charge increased as the laser energy increased and the maximum charge was 530 pC, when the laser energy was 95 mJ at the cathode surface.

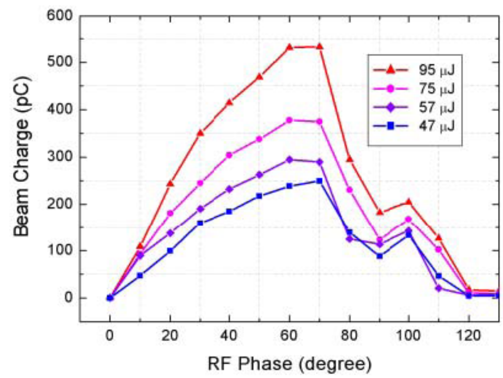

Figure 5: Measured beam charge under various RF phases and laser energies.

SUMMARY

PAL-XFEL will provide 0.3 nm FEL by expanding and upgrading the existing linac up to 3.7 GeV. It will use an in-vacuum undulator. The photo-cathode RF injector is under active R&D. The whole project will proceed in two stages. In the first stage, only a 320 MeV TM will be constructed to prove the validity of PAL-XFEL scheme. The full PAL-XFEL will come only in the second stage.

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