DIAGNOSTIC SYSTEMS FOR THE PAL-XFEL COMMISSIONING

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Abstract

In 2011, an X-ray Free-Electron-Laser project was started in the Pohang Accelerator Laboratory (PAL-XFEL). The construction of the PAL-XFEL was finished at the end of 2015, and the commissioning was started from April 2016. The electron beam energy of 10 GeV was achieved at the end of April and the bunch compression was tried in May. The undulator commissioning was started from June. During the commissioning process, various kinds of instruments were used for the beam parameter monitoring including beam position monitors, beam profile monitors, beam charge monitors, beam arrival-time monitors, and beam loss monitors. This work will introduce the PAL-XFEL diagnostic system which was used in the commissioning process.

INTRODUCTION

The PAL-XFEL is a fourth-generation light source to produce hard X-ray radiation with a femto-second pulse width by using the Self Amplification of Spontaneous Emission (SASE) [1]. In the PAL-XFEL, electron beams with 200 pC can be generated from a photocathode RF gun and accelerated to 10 GeV energy by using a 780 m long linear accelerator. After the linear accelerator, the electron beam passes through a 250 m long undulator section to produce hard X-ray of 0.1 nm wavelength. Finally, the FEL radiation come into the beamline of which length is 80 m long. Figure 1 shows a bird's eye view of the PAL site. The PAL-XFEL is shown as a long line in the left and the storage ring of the PLS-II is shown in the right.

The PAL-XFEL building construction was started from September 2012 and it was finished in December 2014. After that, the installation of the linac, the undulator, and the beamline components were continued to the end of 2015 as shown in Fig. 2. The RF conditioning started from November 2015 and it was continued about six months. The commissioning was started in the mid of April 2016, and 10 GeV electron beam was achieved in the end of April. The first spontaneous radiation of the undulator was obtained on 12th of June, and the first SASE FEL was observed on 14th of June 2016. The wavelength of the SASE FEL radiation was 0.5 nm with the electron beam energy of 4 GeV.

For the successful commissioning of the PAL-XFEL, various kinds of diagnostics along the linac and undulator section were used to measure beam parameters such as the beam position, the beam charge, the beam size, the bunch length, et cetera. These parameters for the beam operation and instruments for measurements of them are listed in Table 1. In this paper, diagnostic system of the PAL-XFEL will be presented. It will include the beam position monitor, the beam profile monitor, the beam charge monitor, the beam arrival-time monitor, and the beam loss monitor.

PAL-XFEL DIAGNOSTICS

Beam Position Monitor

Figure 3 shows the stripline Beam-Position-Monitor (BPM) pickup of the PAL-XFEL. For the beam operation of an accelerator, it is important that the electron beam passes through the center of the quadrupole magnet to keep the beam shape symmetrically, and to make the orbit close to the ideal one as much as possible. In the PAL-XFEL, stripline BPMs were installed along the linear accelerator to monitor the beam position inside the vacuum chamber. The measured resolution of the stripline BPM was 3 μm. For the BPM

Figure 1: A bird's eyes view of the PAL. The PAL-XFEL and the PLS-II are shown in the left and the right, respectively.

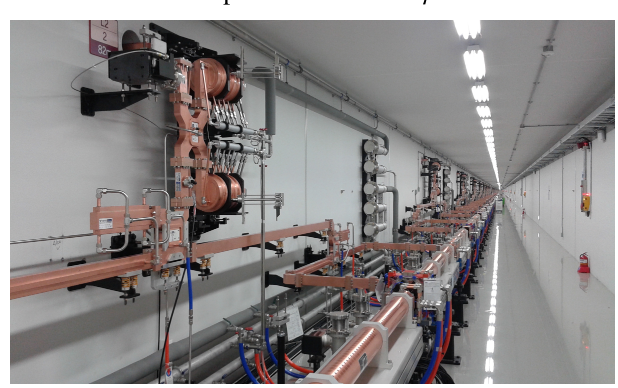

Figure 2: Accelerating structures inside the PAL-XFEL linac tunnel.

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Table 1: Operation Parameters and Measurement Instruments for the PAL-XFEL

Parameter	Instrument
Beam Position	Stripline BPM
	Cavity BPM (Undulator)
Beam Size	Screen Monitor
	Wire Scanner
Bunch Length	Transverse Deflecting Cavity
	Coherent Radiation Monitor
Beam Charge	Turbo-ICT
Beam Arrival Time	Beam Arrival-Time Monitor
Beam Loss	Beam Loss Monitor (Undulator)

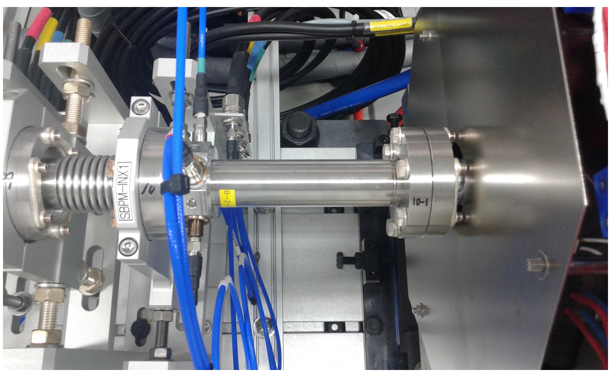

Figure 3: A stripline BPM of the PAL-XFEL linac.

electronics, μTCA-based digital electronics were prepared under the collaboration with the SLAC [2].

In the undulator section, cavity BPMs were installed because of their good resolution. The resolution of the cavity BPM is less than 1 μm so that it can be used for the beam alignment in the undulator section where the electron beam and the radiation should be overlapped, precisely. The PAL and the SLAC have been collaborated for the development of the X-band cavity BPM since 2013 [3]. The cavity BPM pickup was developed in the PAL and the electronics was made in the SLAC. Figure 4 shows a cavity BPM pickup in the PAL-XFEL [4].

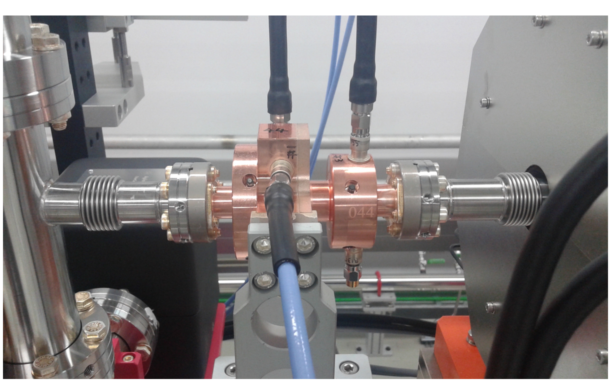

Figure 4: A cavity BPM of the PAL-XFEL undulator section.

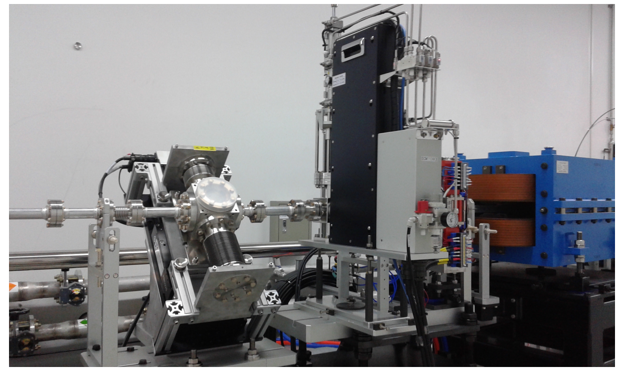

Figure 5: A wire scanner (left) and a screen monitor (right) to measure the transeverse beam profile.

Transverse Profile Monitor

Figure 5 shows a wire scanner (left) and a screen monitor (right) for the transverse profile measurement. In the screen monitor, a two-step pneumatic actuator was used to inject the target holder to the electron beam trajectory. Two kinds of target can be mounted in the target holder for the beam profile imaging. One is a YAG:Ce scintillator and the other is an Al-foil OTR target. The target size is one inch and the thickness is 100 μm and 1 μm for the YAG:Ce and Al-foil, respectively.

The target holder was specially designed to remove the Coherent-Optical-Transition-Radiation (COTR) by using a method developed in the SwissFEL and the European XFEL [5]. The OTR has a very small opening angle with the high energy electron beam, so that the OTR can be avoided if the reflection mirror is miss aligned slightly from the OTR propagation direction. The scintillation light from the YAG:Ce target without the OTR can be reflected to the CCD camera.

In the wire scanner, a tungsten (18 μm thickness) and carbon (34 μm thickness) wires were used in the linac and the undulator section, respectively. The wire is fixed on a frame which is mounted on a 45° tilted translation stage. A linear motor is used in the translation stage to minimize the vibration while the translation stage moving. Simple optical fibers, which were connected to Photo Multiplier Tubes (PMTs), were installed for detectors downstream of the wire scanner.

Longitudinal Profile Monitor

For the bunch length measurement, transverse deflecting cavities, from the RadiaBeam Technologies and the VITZROTECH, were installed after bunch compressors as shown in Fig. 6. The transverse deflecting cavity looks like a normal accelerating column, however, it can generate a transverse kick to the electron beam instead of a longitudinal one. Because of the transverse kick, the head and the tail of the electron beam moves to the plus and the minus direction of the vertical axis, respectively. In this way, time information of the bunch length can be converted to space information of the beam size, and the electron beam makes

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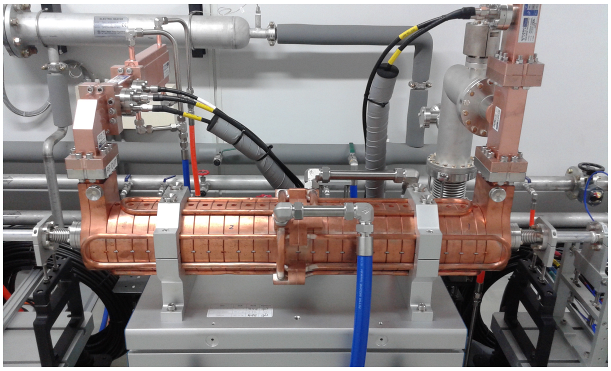

Figure 6: A deflecting cavity for the measurement of the longitudinal bunch length.

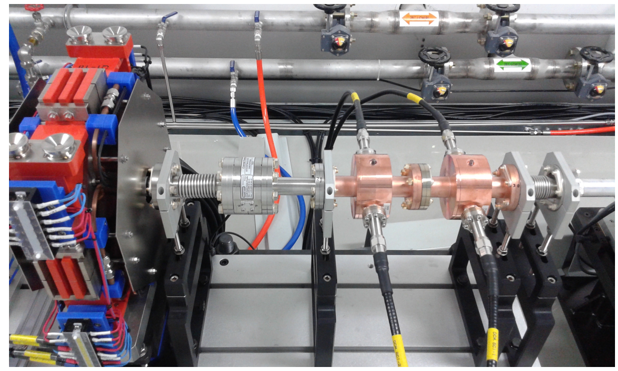

Figure 7: A Turbo-ICT and beam arrival-time monitors of the PAL-XFEL linac.

a long profile image which is corresponding to the bunch length.

Even though the transverse deflecting cavity can measure the absolute bunch length, one should kick the electron beam to the vertical direction and block it to get the beam image for the bunch length measurement. For a non-destructive monitoring of the bunch length, coherent radiation monitors were installed after bunch compressors to measure the relative bunch length.

After the bunch compressor, one can find several kinds of radiation, such as synchrotron radiation, edge radiation, diffraction radiation, et cetera, and their intensities are inversely proportional to the bunch length. Thus, the relative bunch length can be obtained by monitoring the radiation intensity.

A gold coated mirror was installed inside the vacuum chamber after the last bending magnet of the bunch compressor. Reflected radiation is guided into a detector chamber and focused into a pyro detector by using a parabolic mirror. The pyro detector can measure the radiation intensity in the range of the infrared wavelength.

Beam Charge Monitor

Turbo Integrated-Charge-Transformers (Turbo-ICTs) from the Bergoz Instrumentation were installed for the beam charge measurement. The Turbo-ICT has less than 1 pC resolution and showed a good performance for the PAL-XFEL commissioning. Figure 7 shows a Turbo-ICT and beam arrival-time monitors of the PAL-XFEL linac.

Beam Arrival-Time Monitor

One of the advantage of the PAL-XFEL is that a pump-prove experiment is possible. The laser pump excite the sample and the FEL prove can detect the change of the sample. In that case, beam arrival time relative to the reference trigger is important information for the experiment.

The beam arrival-time monitor has a simple cavity structure. When the electron beam passes through it, S-band resonance signal can be generated and IF signal is obtained after a mixing with the reference signal. The IF frequency comes into an Analog Digital Converter (ADC) to analyze the phase and the amplitude. If the electron beam is synchronized with the reference signal exactly, then the phase of the IF signal will remain constant. In this way, the phase jitter gives us information of the arrival time jitter with a 20 fs resolution.

Beam Loss Monitor

Continuous exposure to high energy electron beams can change the magnetic property of the undulator permanent magnet. Thus, we installed a beam loss monitor before every undulator to monitor the beam loss. The beam loss monitor consists of two acrylic (Polymethyl methacrylate, PMMA) rods and two PMT modules. Two rods were transversely installed above and below the vacuum chamber and Cherenkov radiation can be generated in the case of the beam loss. The amplitude of Cherenkov radiation is amplified with the PMT module and measured by using an ADC.

SUMMARY

The PAL-XFEL project was started 2011 and finished at the end of 2015. The commissioning was started in April 2016 and the first SASE FEL was observed at the end of June. For the successful commissioning, various kinds of diagnostic instruments were installed in the PAL-XFEL to measure the beam position, the beam charge, the beam size and the bunch length. The beam arrival time and the beam loss were monitored as well.

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