DIAGNOSTIC SYSTEMS OF THE PAL-XFEL

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Abstract

The Pohang Accelerator Laboratory (PAL) started an x-ray free electron laser project (PAL-XFEL) in 2011 [1]. The construction was finished at the end of 2015 and the commissioning is ongoing from the beginning of 2016. In the PAL-XFEL, an electron beam with 200 pC will be generated from a photocathode RF gun and will be accelerated to 10 GeV by using a linear accelerator. The electron beam will pass through undulator section to produce hard X-ray radiation. For the successful commissioning and beam operation, various kinds of instruments were prepared.

INTRODUCTION

Electron beam parameters, such as beam positions, energy, charge, transverse beam size, bunch length, and arrival time, should be measured and monitored for the operation of the PAL-XFEL. Figure 1 shows the PAL-XFEL layout and positions of the diagnostic instruments. Various kinds of diagnostics are distributed along the linac and undulator section to measure beam parameters. Especially after the bunch compressor, servral instruments are integrated to check beam parameters because important changes can happen in beam properties during the bunch compression.

Beam Position Monitors (BPMs) were installed to measure the beam position along the linac and the undulator section. Screen monitors were prepared to measure beam sizes. Wire scanners were added in the case that screen monitors cannot be used because of the Coherent Optical Transition Radiation (COTR). Comercial Integrated-Current-Transformers (Turbo-ICTs, Bergoz) were installed to measure the beam charge. The bunch length can be measured by transverse deflecting cavities and monitored by coherent radiation monitors. Beam loss monitors were installed in every undulator to monitor the beam loss to protect undulator permanent magnets. The beam arrival time will be checked by arrival time monitors. The diagnostic instruments of the PAL-XFEL are listed in Table 1.

In this paper, stripline BPMs and screen monitors of the PAL-XFEL will be explained in detail. It will cover from design, fabrication, test result to the real measurement results of the beam signal.

BEAM POSITION MONITOR

The BPM is the most important diagnostics in the PAL-XFEL. For the beam operation of an accelerator, it is very 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, 160 stripline BPMs will be installed along the linear accelerator to monitor the beam position inside the vacuum chamber.

Table 1: Measurement Parameters, Instruments, and Number of Diagnostics for the PAL-XFEL

Parameter	Instrument	Number
Position	Stripline / Cavity BPM	160 / 49
Charge	Turbo-ICT	10
Beam Size	Screen Monitor	54
Bunch Length	Transverse Cavity	3
Arrival Time	Arrival Time Monitor	10

For the design of the stripline BPM, inner and outer diameters are considered first. 59 BPMs were installed inside the quadrupole magnet to reduce the space for the stripline BPM, so that the outer diameter of the stripline BPM is limited to the inner diameter of the quadrupole magnet. At the same time, there should be enough space for the electron beam pass, so that innor diameter of the BPM was decide to 22 mm, considering of the 19 mm inner diameter of the S-band accelerating column. For the stripline design, impedance mataching was carefully consided. If there is a impedance mismatching in the stripline BPM, that will be a main source of attenuation and reflection of the signal. Thus the stripline width and height were carefully selected to have 50 Ω impedance.

Figure 2 shows a stripline BPM geometry with 2.75" CF flanges. The inner diameter of the stripline is 22 mm and the outer diameter is 30 mm. The length of the stripline is 120 mm and the coverage angle of the 4 striplines is 26° (7.2% of 360°). One end of the stripline is connected to the SMA connector and the other one is shorted to the vacuum chamber. Figure 3 shows the simulation result of the electron beam signal from the stripline BPM. No reflection can be found after the main beam in the signal time profile. This means that the impedance is well matched.

The performance of the BPM pickup was check by using a BPM test stand which is shown in Fig. 4 [2, 3]. The BPM test stand consists of a two dimensional translation stages for the BPM pickup position change, a wire which is connected to a signal generator, a BPM electronics, and a control computer. The BPM pickup can be moved by step-motors, and the position of each step-motor can be measured by encoder with resolution of 1 μm. 500 MHz sinusoidal wave is made by a signal generator and the wave is dumped to a terminator

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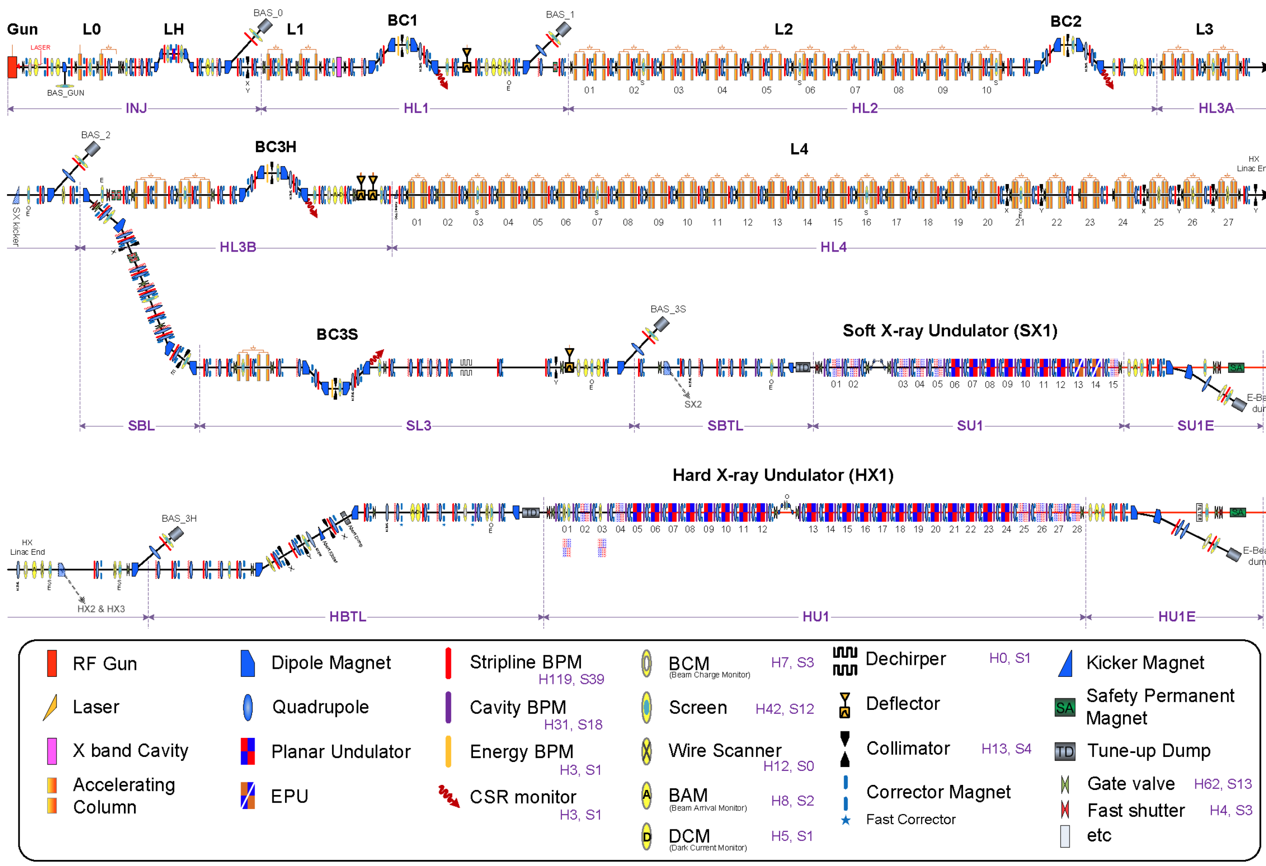

Figure 1: PAL-XFEL layout and diagnostics

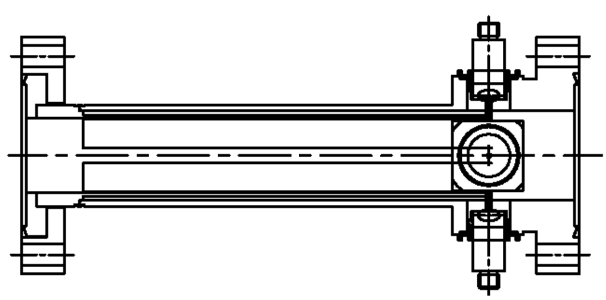

Figure 2: Cross-section of the PAL-XFEL stripline BPM

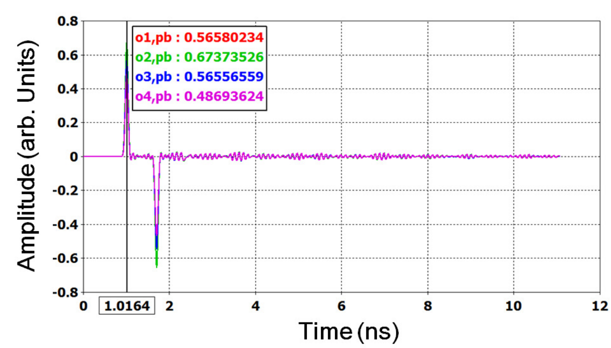

Figure 3: Time profile of the beam signal from the CST simulation of the stripline BPM

through 0.5 mm thickness wire which is passing through the BPM pickup. The BPM electronics (Libera single pass, Instrumentation Technologies) takes the signals from four SMA connectors of the BPM pickup. Using these four signals, the BPM electronics calculates the wire position which is corresponding to the beam position inside the accelerator. The wire test stand is fully automated by a personal computer which has a Labview based control program.

Figure 5 shows measurement results of the wire positions when a 2.75”-CF-flange BPM moved along $x = 0$ and $y = 0$ lines. The horizontal and the vertical axis shows encoder readings of the wire position and the measured position of the wire by using the BPM electronics, respectively. Encoder readings and BPM measurements are same to each other within ±4 mm range, and BPM measurements show a good linearity. After ±4 mm, however, they were saturated.

For the BPM electronics, μTCA based digital electronics were prepared under the collaboration with the SLAC. Recently, the Stanford Linear Accelerator Center (SLAC) introduced a high-performance BPM electronics based on the μTCA technology [4]. The μTCA is widely mentioned as a next-generation control platform, and the PAL decided to use it for the PAL-XFEL BPM system. Figure 6 shows a μTCA based BPM electronics from the SLAC. The μTCA BPM electronics consists of a μTCA crate (Elma), a cen-

Figure 4: A picture of the wire test stand. A BPM translation stage with wire holder, a motor controller, BPM electronics, and a control computer are shown.

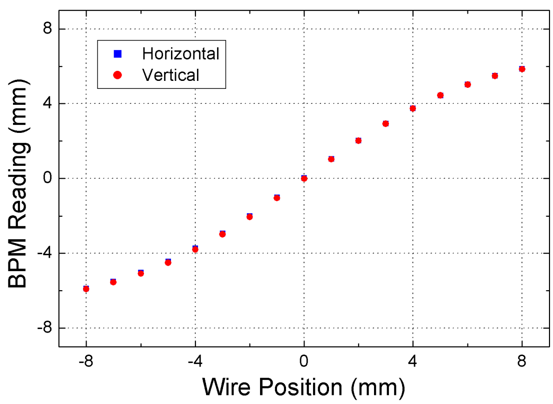

Figure 5: Encoder readings versus BPM readings of the wire position. Here, a 2.75”-CF-flange BPM was used and a linear response was obtained in the range of ±4 mm.

tral processing unit (CPU, Concurrent), a channel manager (NAT), a power module (Wiener), seven Analogue Digital Converter (ADC SIS8300, Struck) with a rear transition module (SLAC), and one PMC carrier card (Vadatech). In addition to that a SLAC designed EVR fan-out module is used. The input frequency and the bandwidth are 300 MHz and 30 MHz, respectively and ADC has 250 MHz sampling frequency and 16 bit resolution.

For the performance test, 300 MHz signal was generated from a signal generator and it passed through the 4 way divider. Divided signals were sent to the BPM electronics. In an ideal case, the BPM reading should be same in every measurements, because the amplitude ratio of 4 signals are same in every time. However, they has some fluctuation in a real measurement and the width of the Gaussian fitting curve gives us the electronics resolution. The measured resolution was 1.9 μm and 1.7 μm for the horizontal and the vertical directions, respectively.

SCREEN MONITOR

In addition to the BPMs, a screen monitor is one of the most important instrument in the PAL-XFEL. The screen

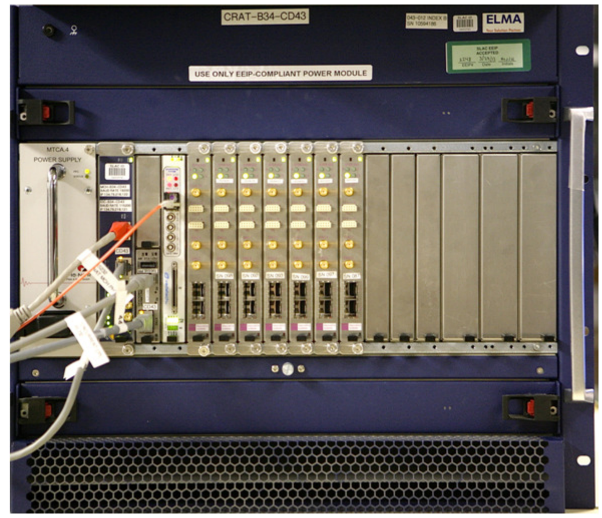

Figure 6: A front picture of the μTCA based BPM electronics

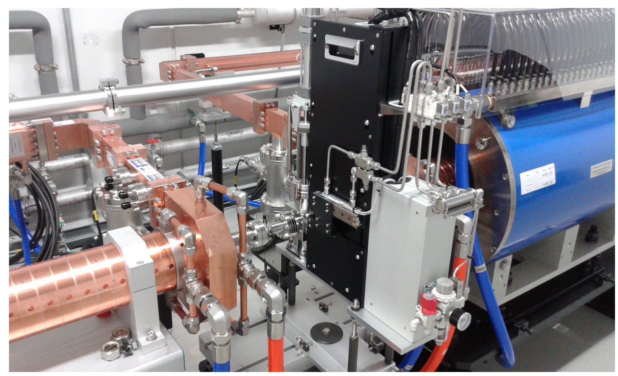

Figure 7: A picture of the PAL-XFEL screen monitor between two accelerating columns

monitor can show the trasverse size and the profile of the electron beam, so that it can provide important information inside the accelerator which can not be provided by BPMs. BPMs can measure the beam position precisely, but it just calculate the center of charge. If the electron beam has abnormal profile, such as an over-focused electron beam, then the BPM can not notice any problem in the electron beam operation.

Figure 7 shows a screen monitor which is installed between two acceleration columns. The screen monitor consists of a vacuum chamber which contains a target holder, a two-step pneumatic actuator to inject the target holder to the electron beam trajectory, a black box which has optics and a GigE CCD camera next to the vacuum chamber, and a controller. In the target holder, two kinds of target can be mounted for the beam profile imaging as shown in Fig. 8. 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 20 μm for the YAG:Ce and Al-foil, respectively. Generally, the YAG:Ce scintillator gives more intense light to get a clear beam image but the error of the OTR measurement

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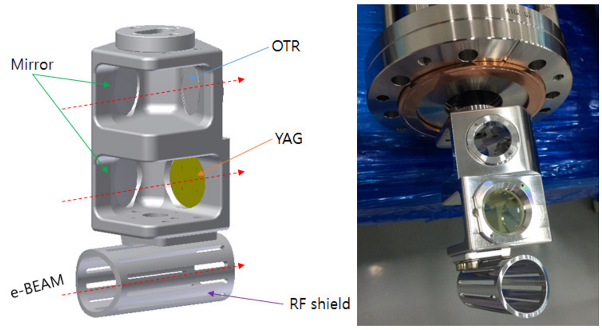

Figure 8: A 3D model (left) and a picture (right) of a target holder in the PAL-XFEL screen monitor

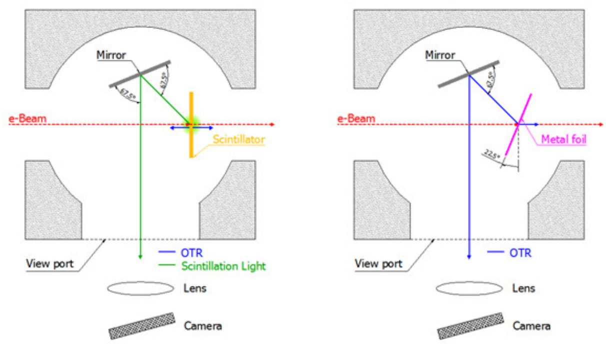

Figure 9: Schematic layout of the target holder. A YAG:Ce (left) and an OTR target (right) are shown with mirrors.

is smaller when the beam size is tens of μm because of the grain size of the YAG:Ce.

In addition, the COTR is a major issue in the screen monitor of XFEL machines. When the electron bunch length is reduced down to fs order, the OTR of the visible wavelengh range becomes a coherent one and its intensity increases dramatically. The intensity of the coherent radiation is propotional to the squre of the electron beam charge while that of the uncoherent one is linearly depend on the charge. When the COTR happens, the beam image becomes a saturated one and the beam size measurement is impossible.

To solve this problem, the target holder was specially designed to remove the COTR effect 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 OTR can be avoided if there is enough angle between the OTR propagation direction and a mirror to reflect scintillation light from the target. Figure 9 shows the inside layout of the target holder. The YAG:Ce (left) and the OTR target (right) are shown with mirrors. Note that there is 45° angle between the electron beam direction and the mirror position in the YAG:Ce target case. However, the bigger angle between electron beam and the mirror, the more errors can be produced in the beam size measurement so that a better geometry with a smaller angle will be tried as a next step.

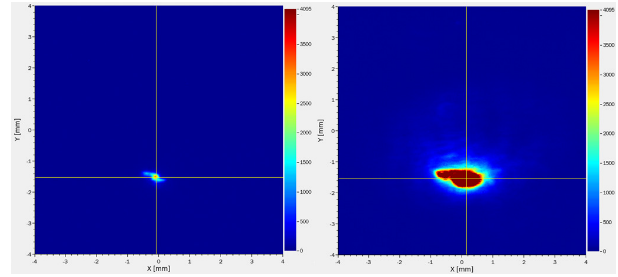

Figure 10: Beam images of the YAG:Ce (left) and the OTR target (right) after the bunch compression. COTR can be noticed in the beam image of the OTR target.

On April 14, 2016, the commissioning of the PAL-XFEL was started and 10 GeV electron beam was acheived in the end of April. After that, the bunch compressor was turned on and beam images were obtained to check the COTR problem. Figure 10 shows images from the YAG:Ce (left) and the OTR target (right) after the bunch compressor. The beam image of the YAG:Ce target was not saturated when the COTR was clearly noticed from the OTR target.

SUMMARY

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 can be monitored as well. BPMs were carefully desinged with the CST simulation for the better resolution and impedance matching, and checked with the wire test stand after the fabrication. μTCA based BPM electronics were prepared under the collaboration with the SLAC. A YAG:Ce and an Al-foil target were mounted in the screen monitor. The target holder were specially desinged to avoid the COTR problem. Its performance was checked with the bunch compressor during the commissioning of the PAL-XFEL.

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