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STRIPLINE BEAM POSITION MONITOR FOR THE PAL-XFEL

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Abstract

The X-ray Free Electron Laser of the Pohang Accelerator Laboratory (PAL-XFEL) produces 0.1 nm wavelength X-ray with a femtoseconds pulse width by using the self-amplification of spontaneous emission (SASE). For the successful commissioning and the stable operation of the PAL-XFEL, Beam Position Monitors (BPMs) are most the impor-tant instrument among the various kinds of electron diagnos-tic tools. In this work, the BPM system for the PAL-XFEL is introduced. From the pickup to the electronics, details of the BPMs are presented.

INTRODUCTION

After upgrade of the Pohang Light Source (PLS-II), the Pohang Accelerator Laboratory (PAL) had rushed into the construction of the X-ray Free Electron Laser (PAL-XFEL) [1]. The project period was from 2011 to 2015 and the project budget was 400-million-dollar. In the PAL-XFEL, an electron beam with 200 pC charges can be generated from a photocathode RF gun with 60 Hz repetition rate and can be accelerated to 10 GeV energy by using a 780 m-long linear accelerator (linac). After the acceleration, electron beams pass through a 250 m-long undulator section to produce 0.1 nm-wavelength hard x-ray with the self-amplification of spontaneous emission (SASE) [2-4].

To send an electron beam from the gun to the linac end, transverse beam-position measurements along the linac are the most important issue in the beam diagnostics. The electron beam should pass through the center of the quadrupole magnet to keep the beam size and shape symmetrically and to make the orbit as close as possible to the ideal one. In this reason, a good performance of the Beam Position Monitor (BPM) is a critical element for the stable operation of the PAL-XFEL.

The electron beam of the PAL-XFEL has a small charge (20 pC ~ 200 pC) and a short bunch length (50 fs ~ 5 ps). In addition, In the PAL-XFEL, different BPM resolutions were required for the linac and the undulator section. 10 µm resolution is enough for the linac operation. On the other hand, 1 µm resolution is needed for the beam based alignment of the undulator section. Under these requirements, a stripline and a cavity BPMs were selected for the linac and undulator BPMs. In this paper, we introduce the stripline BPM of the PAL-XFEL. It includes the details of the pickup design, and measurement results of the resolution by using the electron beam. The hardware and the software of the BPM electronics are presented, as well.

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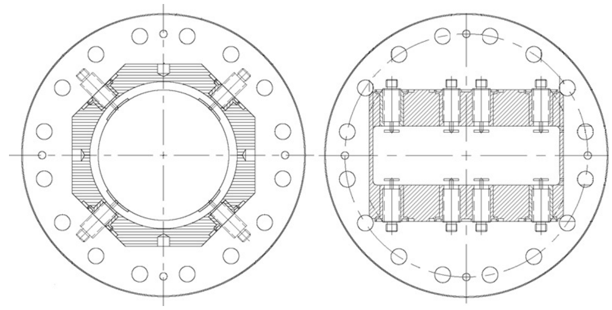

Figure 1: Transverse cross-sections of the circular (left) and the rectangular (right) chamber BPMs with CF 6 inch flanges.

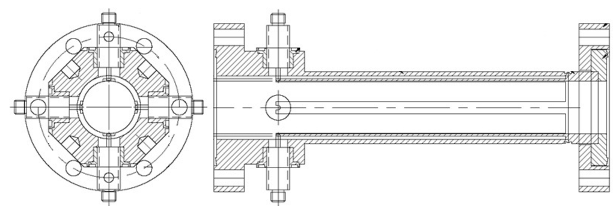

Figure 2: The transverse (left) and the longitudinal (right) cross-sections of the stripline BPM with CF 2.75 inch flanges.

PAL-XFEL STRIPLINE BPM

The stripline BPM in the linac can be separated into two groups. One is the circular chamber BPM and the other is the rectangular one for the bunch compressor. Most of the linac components have circular chambers as the aperture of the accelerating column. In the bunch compressor, however, the beam size can be increased to the horizontal direction because of the dispersion, and rectangular vacuum chambers were introduced. Even in the case of the rectangular vacuum chamber, CF flanges were used for the connection with other linac components. CF 2.75 inch, 4.5 inch, and 6 inch flanges were selected for the circular chamber, and CF 6 inch and 8 inch flanges were used for the rectangular one in the bunch compressor. Figure 1 shows transverse cross-sections of the circular and the rectangular chamber BPMs with CF 6 inch flanges.

BPMs with CF 2.75 inch flanges are widely distributed in the linac and its number is much bigger than that of BPMs with other types of flanges. A large number means that there are many requirements as well, and BPMs with CF 2.75 inch flanges have various lengths because of the limited space in the linac. Especially in the injector, lots of components were packed in a short space to minimize the emittance grow-up. Thus, the length of the BPM was reduced to a minimum

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Table 1: Summary of PAL-XFEL BPMs

Position	Flange (in)	Chamber	I.D. (mm)	Length (mm)	Angle (°)	Hard X	Soft X	Total
Linac	2.75	Circular	26.4	90	0	4	-	4
Linac	2.75	Circular	26.4	165	0	38	32	70
Linac	2.75	Circular	26.4	230	0	5	-	5
Linac	2.75	Circular	26.4	295	0	45	-	45
Linac	2.75	Circular	26.4	320	0	7	-	7
Linac	2.75	Circular	26.4	350	0	1	1	2
Linac	4.5	Circular	44	180	45	15	5	20
Dump	6	Circular	79	180	45	2	1	3
B.C.	6	Rectangular	100×31.6	180	-	2	1	3
B.C.	8	Rectangular	150×31.6	180	-	1	-	1
Total	-	-	-	-	-	120	40	160

value (90 mm). Where the space problem was released in the linac, 165 mm length BPMs with CF 2.75 inch flanges were installed.

In the linac, a quadrupole magnet can be found between two accelerating columns to make the FODO lattice, and the BPM was installed in the quadrupole magnet to save the space. This requirement imposed strong boundary conditions for the BPM geometry to the longitudinal and the transverse direction, simultaneously. To the longitudinal direction, the BPM should be long enough for the quadrupole magnet installation. At the same time, however, the total length of the BPM should be reduced down as much as possible for other components in the linac. BPM lengths with CF 2.75 inch flanges were decided to 230 mm, 295 mm, 320 mm, and 350 mm depend on quadrupole magnet lengths.

To the transverse direction, the outer diameter of the stripline BPM chamber was limited to less than 30 mm, owing to the quadrupole magnet pole. On the other hand, the inner diameter of the stripline was decided to 22 mm, considering of the 19 mm aperture of the S-band accelerating column. Thus, the stripline and the vacuum chamber should be placed in the space between 22 mm and 30 mm to the radial direction. For the decision of the width and the thickness of the stripline, the impedance matching was considered carefully, because the attenuation and the reflection of the beam signal can be increased when the impedance matching is poor. Figure 2 shows the transverse and the longitudinal cross-sections of the BPM with CF 2.75 inch flanges.

Circular chamber BPMs with CF 4.5 inch and 6 inch flanges and rectangular chamber BPMs with CF 6 inch and 8 inch flanges have the same length of 180 mm. These BPMs were installed in the energy spectrometer, the beam transport line (BTL), or the beam dump, and no space limitation was in there. Even though BPMs have various lengths to the longitudinal direction, the stripline length in them was all the same as 120 mm, except that of the 90 mm length BPM. Parameters of PAL-XFEL BPMs are summarized in Table 1.

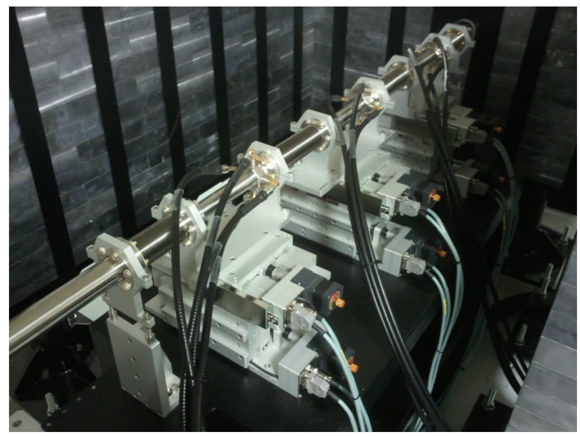

Figure 3: The BPM test stand in the injector test facility. Three BPMs have the same separation along the beam direction and each BPM is installed on a two-dimensional translation stage.

BPM PICKUP RESOLUTION

After fabrication of prototype BPMs, the resolution of the pickup was measured by using the electron beam. In 2012, the Injector Test Facility (ITF) was installed in the PAL to check the performance of the PAL-XFEL injector [5]. It consists of a photocathode RF gun, two accelerating columns, and diagnostic systems including BPMs, screen monitors for the beam size measurement, and a transverse deflection cavity for the bunch length measurement. In addition, at the end of the ITF, a BPM test stand was installed to check the performance of the BPM system as shown in Fig. 3.

In the BPM test stand, three BPMs were installed on two-dimensional stages so that BPMs can be moved to the horizontal and the vertical directions, independently. The distance between the first and the second BPMs are equal to the distance between the second and the third ones, and the BPM resolution was obtained by the three BPMs method. Figure 4 shows the measurement result of the BPM resolution. The horizontal and the vertical axis show the second BPM reading and the calculation result from the first and the third

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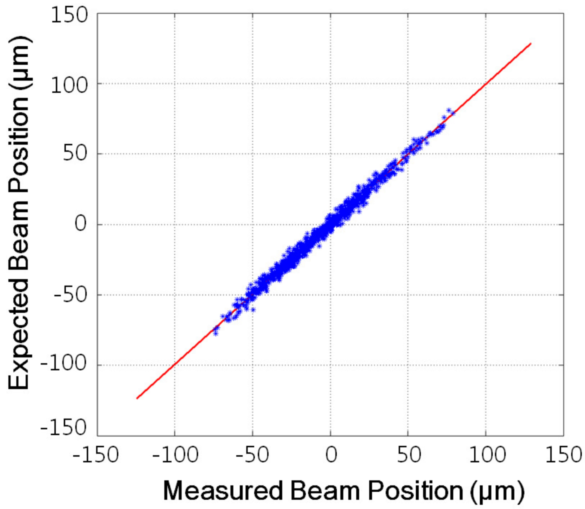

Figure 4: Measured beam positions of the second BPM versus expected beam positions from the first and the third BPM readings in the BPM test stand. The width of the blue dot distribution is the resolution of the BPM system and the measured resolution was less than 3 µm with 200 pC charge.

BPMs, respectively. The red line is an ideal case when second BPM reading is equal to the calculation result from the first and the third BPMs. In reality, however, measurement results (blue dots) are not equal to calculation results, and the width of the blue dot distribution gives us the resolution of the BPM system. Note that the electron beam trajectory may have fluctuations during the measurement, but they are measured in all BPMs, so that they can be canceled out. The measured resolution of the CF 2.75 inch flange BPM was less than 3 µm in both planes with the electron beam charge of 200 pC. The same method was applied to CF 4.5 inch and 6 inch flange cases, and the measured resolutions were 5 µm and 7 µm, respectively. These measurement results meet the requirement of the PAL-XFEL BPM resolution of less than 10 µm.

BPM ELECTRONICS

The BPM electronics calculates the beam position by using pickup signals and its performance is critical for the good resolution of the beam position measurement. Recently, the Stanford Linear Accelerator Center (SLAC) introduced a high-performance BPM electronics based on the µTCA technology [6]. The µTCA had been widely mentioned as a next-generation control platform, and the PAL decided to use it for the PAL-XFEL BPM system. Figure 5 shows a µTCA based BPM electronics from the SLAC. The µTCA BPM electronics consists of a crate (Elma), a central processing unit (CPU, Concurrent), a channel manager (NAT), a power module (Wiener), seven Analogue Digital Converter (ADC) (Struck, SIS8300) with a rear transition module (SLAC), and one PMC carrier card (Vadatech). In addition to that, the SLAC designed EVR fan-out module is used. The input frequency and the bandwidths are 300 MHz and 30 MHz,

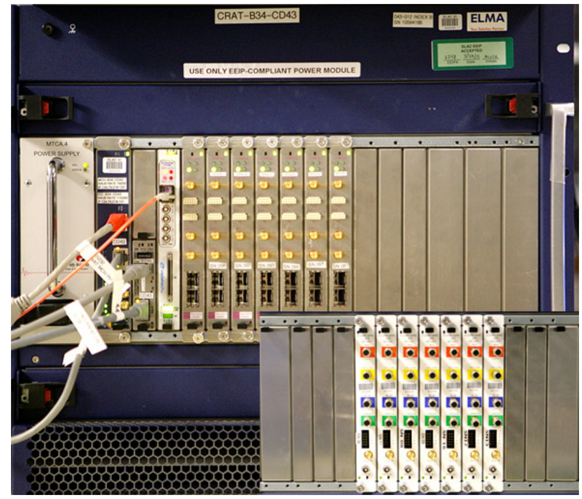

Figure 5: A picture of the µTCA BPM electronics (front and rear).

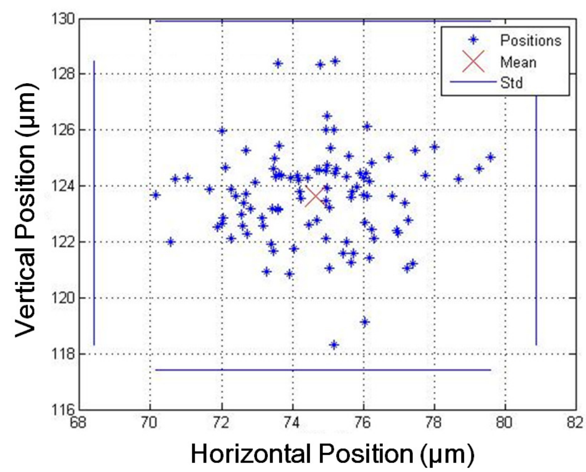

Figure 6: One hundreds points of the BPM reading when input signals had the same amplitude ratio. The width of distribution showed 1.9 µm and 1.7 µm resolution to the horizontal and the vertical directions, respectively.

respectively. The ADC has 250 MHz sampling speed and 16-bit resolution.

Figure 6 shows the resolution measurement result of the µTCA BPM electronics. A 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 to calculate the beam position. In an ideal case, beam positions should be same in all measurements, because the amplitude ratio of 4 signals is same in every time. However, they have fluctuation in real measurements 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.

The BPM electronics calculates the beam position after reading of four stripline signals. In this process, different equations are used for the calculation depend on BPM geometries. A different BPM geometry, however, is nothing

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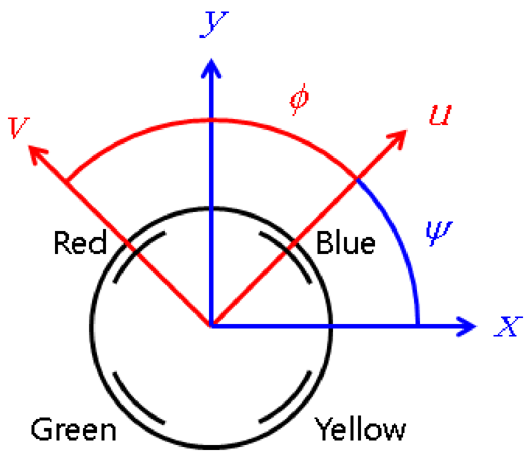

Figure 7: Coordinate systems for the beam position measurement.

but a coordinate transformation, and the µTCA electronics uses u and v coordinates for the beam position calculation as shown in Fig. 7. Note that u and v coordinates are exactly matched with the stripline positions inside a BPM. From u, v coordinates, one can get the beam position in x, y coordinates by first scaling of u, v which are given by

$$u = u \times u_{scale} + u_{offset} \quad (1)$$

$$v = v \times v_{scale} + v_{offset}. \quad (2)$$

Next, a rotation is applied by using

$$x_{raw} = a_{11} \times u + a_{12} \times v \quad (3)$$

$$y_{raw} = a_{21} \times u + a_{22} \times v \quad (4)$$

where $a_{11} = \sin(\psi - \phi)/\sin\psi$, $a_{12} = \sin\phi/\sin\psi$, $a_{21} = -\cos(\psi - \phi)/\sin\psi$, and $a_{22} = \cos\phi/\sin\psi$. Here, ψ is the rotation of u, v axes against x, y axes. ϕ is the angle between the stripline axes when conformally mapped into a circular domain. In the case of normal BPMs, ϕ is 90° but it may differ from that for rectangular BPMs which is used in the bunch compressors. Then scale and offset in the x and y domain are applied by

$$x = x_{raw} \times x_{scale} + x_{offset} \quad (5)$$

$$y = y_{raw} \times y_{scale} + y_{offset}. \quad (6)$$

Input parameters of the coordinate transformation can be changed in the control panel of the BPM electronics as shown in Fig. 8. In the control tab, x and y offset settings, x and y scale settings, the rotation and the axes angle settings can be applied. Scale setting of u, v, and u/v can be done in the calibration tab.

SUMMARY

For the PAL-XFEL linac, a stripline type BPM is selected for the BPM pickup considering the small charge and the

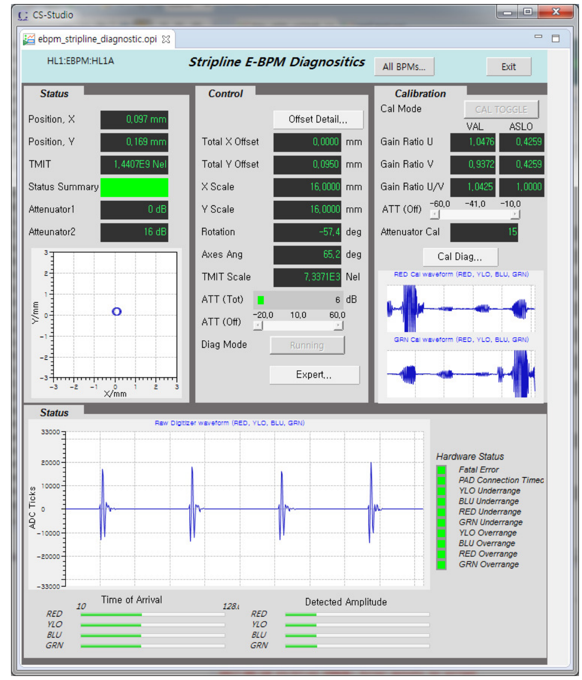

Figure 8: The control panel of a stripline BPM electronics.

short bunch length of the electron beam. The circular and the rectangular chamber were used for BPM bodies and the rectangular chamber was introduced in the bunch compressor. CF 2.75 inch, 4.5 inch, 6 inch and 8 inch flanges were selected for connections with other components and BPMs with CF 2.75 inch flanges were mainly used in the linac. In many cases, BPMs with CF 2.75 inch flanges were installed in the quadrupole magnet and the BPM geometry was strongly affected by it. A BPM electronics, which is based on µTCA, was installed under the collaboration with SLAC. The µTCA electronics showed a good performance, in addition to the advanced method for the beam position calculation.

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